

Chiedere alla polvere

Introduzione al Modello Standard della Fisica delle particelle elementari

International Masterclasses hands on Particle Physics
Laboratori Nazionali di Frascati

F. Dettori

(Università degli Studi di Cagliari e INFN Cagliari)





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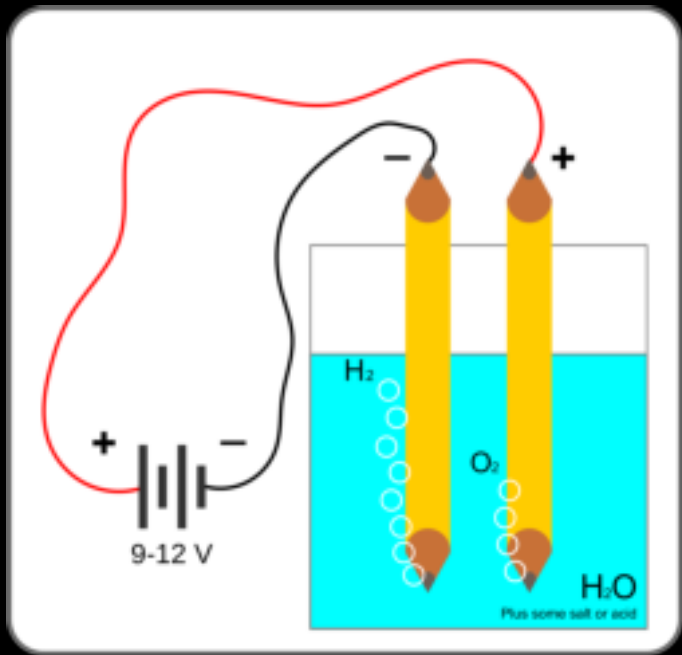


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Legge delle proporzioni definite: *Quando due o più elementi reagiscono a formare una data sostanza, si combinano sempre secondo proporzioni in massa definite e costanti.*

Legge delle proporzioni multiple o di Dalton *Se due elementi formano più di un composto, i rapporti tra le masse del secondo elemento, combinati con una massa fissa del primo, stanno tra loro in rapporti pari a frazioni tra numeri interi piccoli.*



$$M = \frac{AQ}{Fz} \quad M = Nm$$
$$m = \frac{A}{N_A} \quad e = F/N_A$$

$$Q = Nze$$

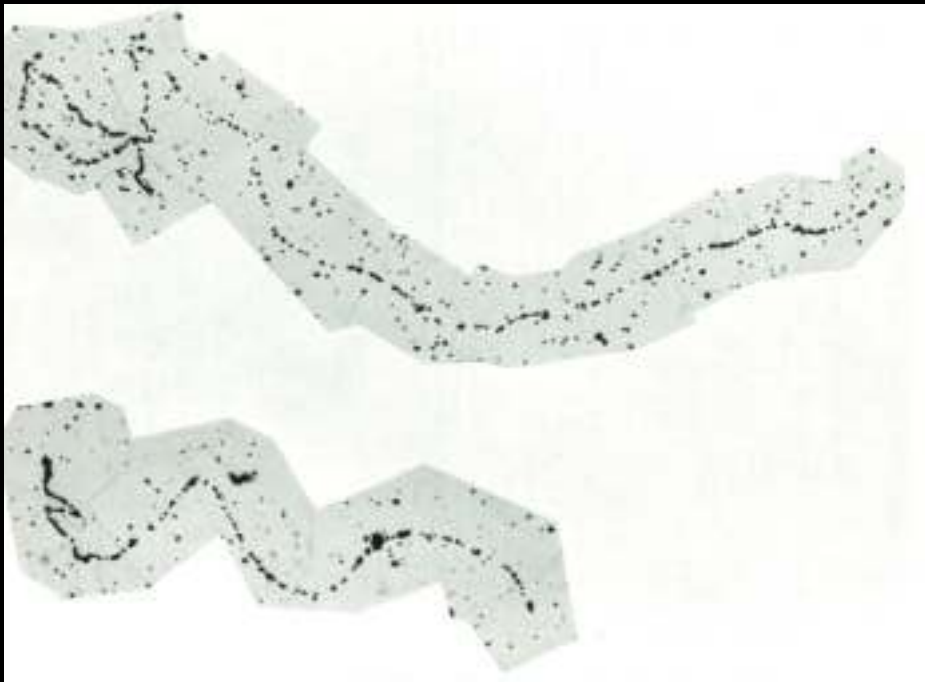


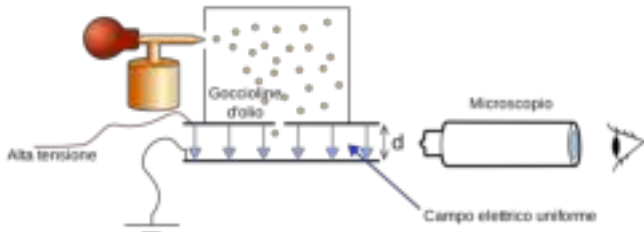


$$F = ma = m \frac{v^2}{R} \quad F = e(E + vB)$$

$$R = \frac{mv}{eB}$$





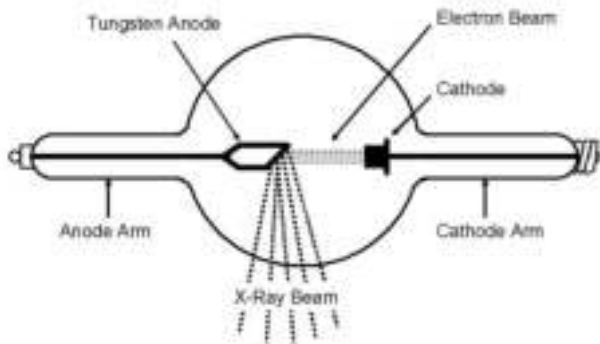


$$F = ma = mg \quad F = eE$$

$$F_A \propto r$$

$$m = \rho V = \frac{4}{3}\pi r^3 \rho$$



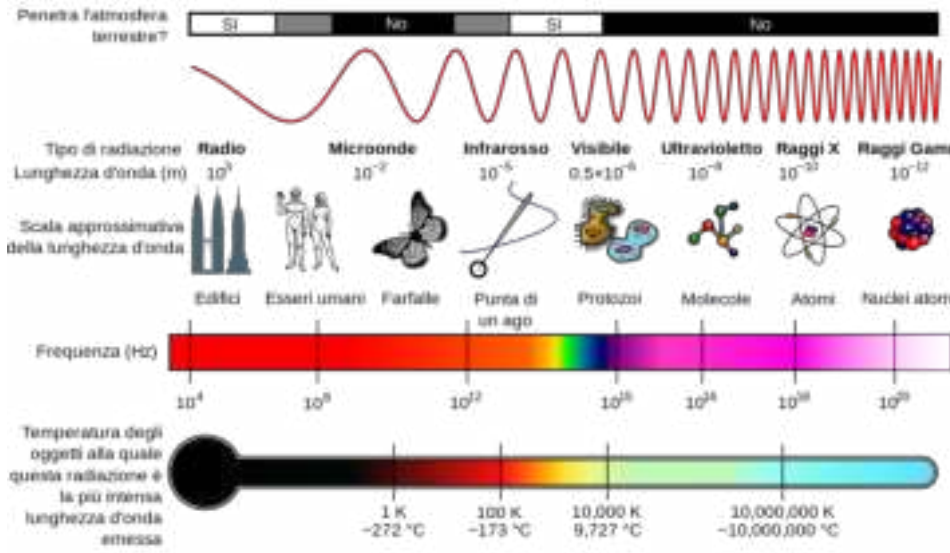


Hand and fingers 1898



*Prepared by Prof. DeBorja
Tracy, M.D.*





$$\alpha \quad \beta \quad \gamma$$

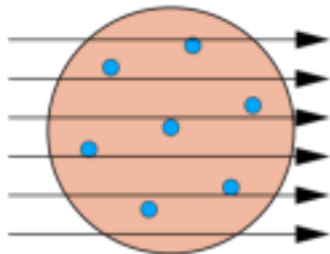
$$N = N_0 e^{-t/\tau}$$



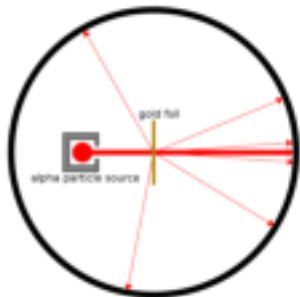
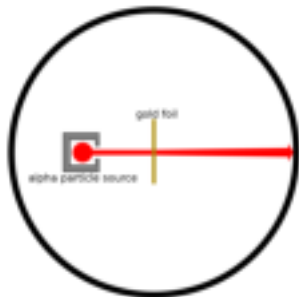
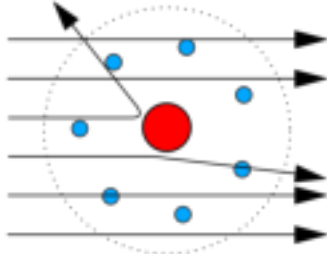




THOMSON MODEL



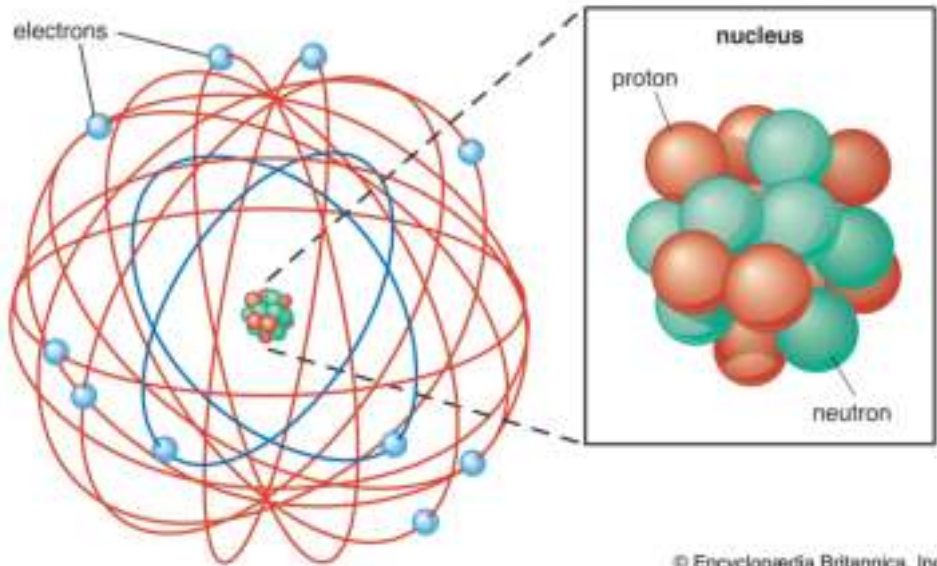
RUTHERFORD MODEL



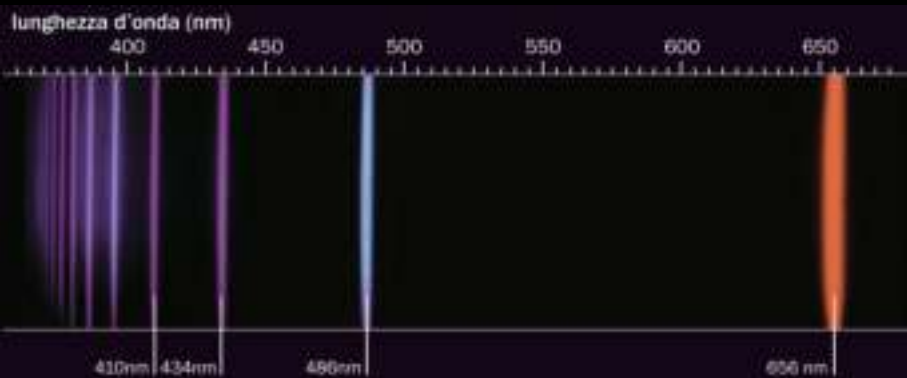
observed result

$$E = \frac{1}{2}mv^2 \quad E = k\frac{qQ}{r}$$

$$r = 2k\frac{qQ}{mv^2}$$



$$E = h\nu$$



$$\frac{1}{\lambda_{n,m}} = Ry \left(\frac{1}{n^2} - \frac{1}{m^2} \right)$$

$$E = \sqrt{m^2 c^4 + p^2 c^2}$$

$$m = 0 \Rightarrow E = pc$$

$$v = 0 \Rightarrow E = mc^2$$

$$E = h\nu = pc$$

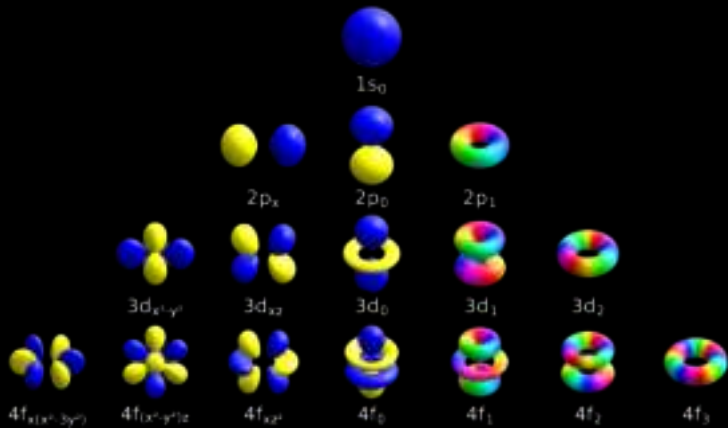
$$p = \frac{h\nu}{c} = \frac{h}{\lambda} \quad \Rightarrow \quad \lambda = \frac{h}{p}$$

$$\psi = \psi(A)\psi(B)$$

$$\psi_S = \psi_{Caio}(A)\psi_{Tizio}(B) + \psi_{Caio}(B)\psi_{Tizio}(A) \quad \text{Simmetrico}$$

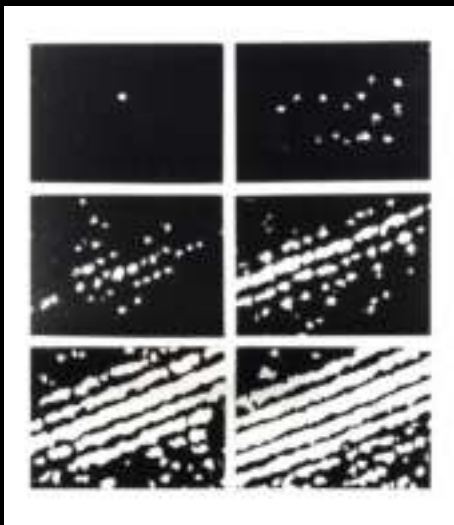
$$\psi_A = \psi_{Caio}(A)\psi_{Tizio}(B) - \psi_{Caio}(B)\psi_{Tizio}(A) \quad \text{Antisimmetrico}$$

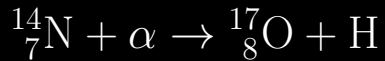
Principio di esclusione di Pauli *Due fermioni non possono occupare simultaneamente lo stesso stato quantico.*











Neutronografia di una caffettiera

<https://www.youtube.com/watch?v=VESMU7JfVHU>

Il Modello Standard a inizio '900?

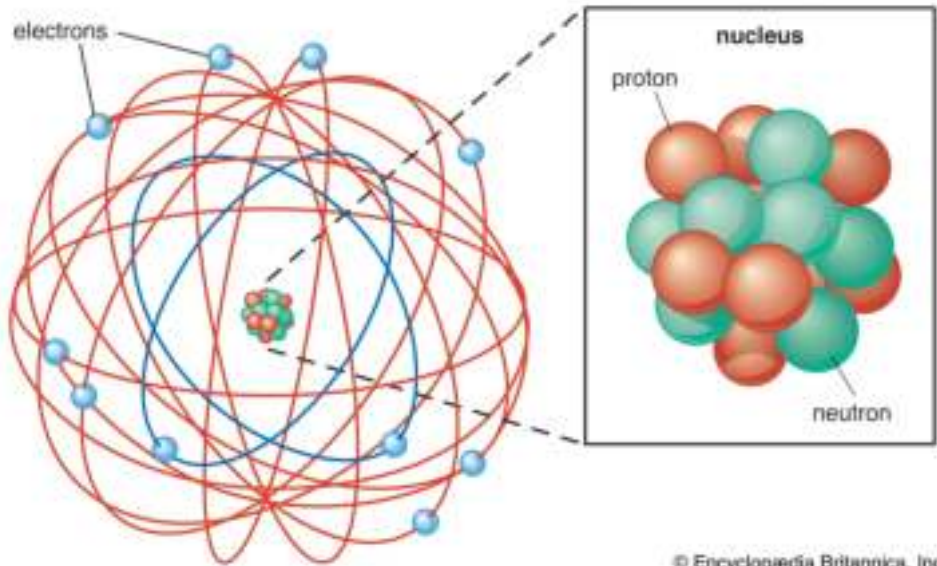
	e^-	n	p	γ
Carica	-1	0	+1	0
Spin	1/2	1/2	1/2	1
Massa (MeV)	0.511	939	938	0

Il Modello Standard a inizio '900?

	Fermioni			Bosoni
	e^-	n	p	γ
Carica	-1	0	+1	0
Spin	1/2	1/2	1/2	1
Massa (MeV)	0.511	939	938	0
	Materia			Interazione

$$E = h\nu$$

$$E = \sqrt{m^2c^4 + p^2c^2}$$

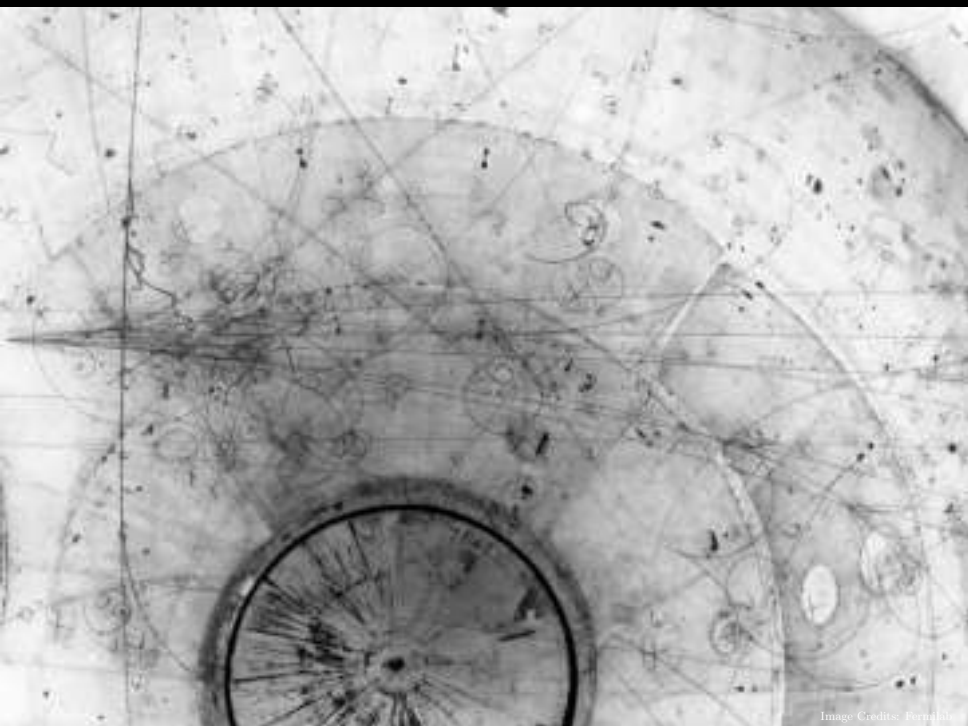




Camera a Nebbia

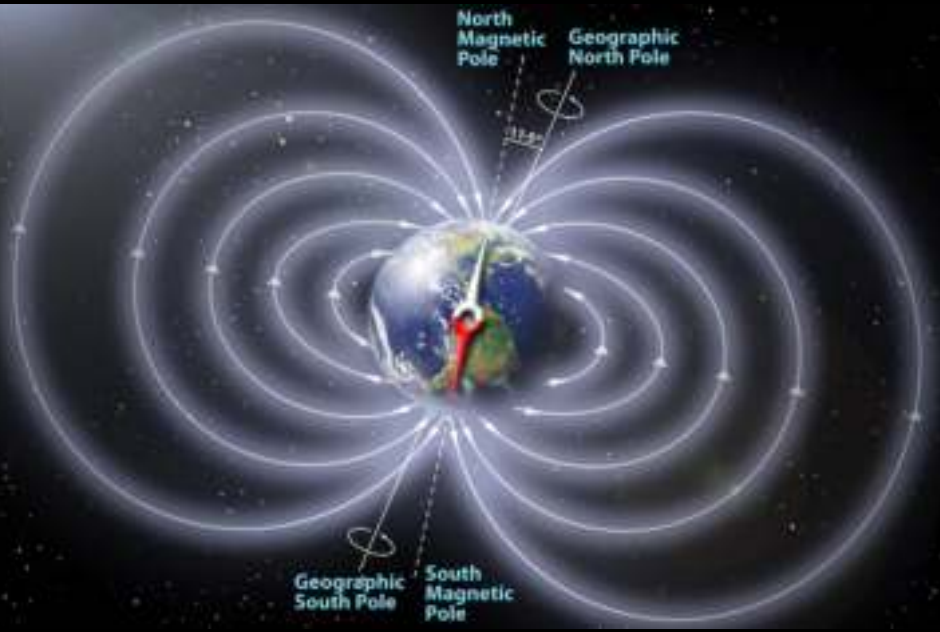
<https://www.youtube.com/watch?v=i15ef618DP0>







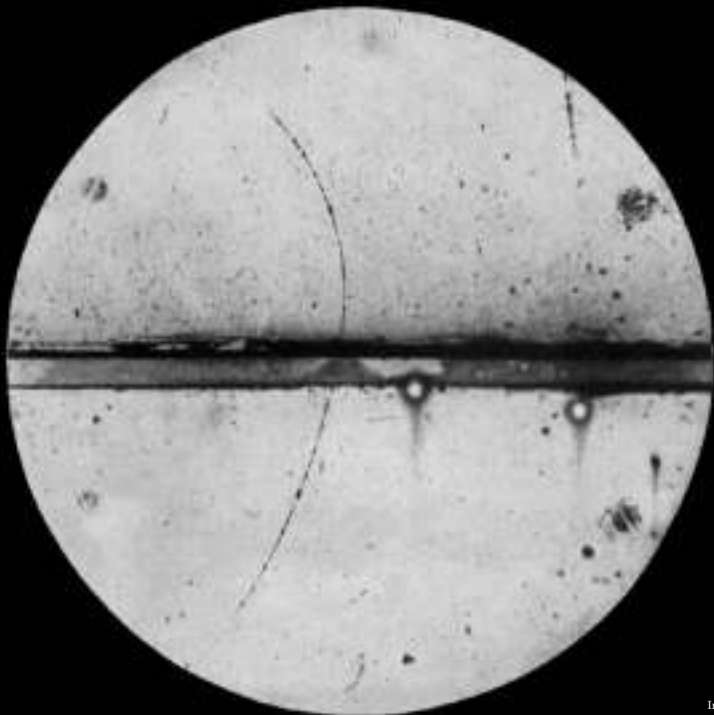


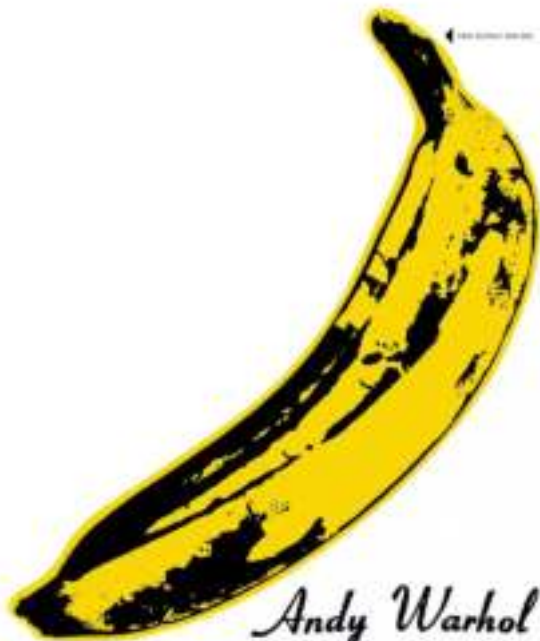




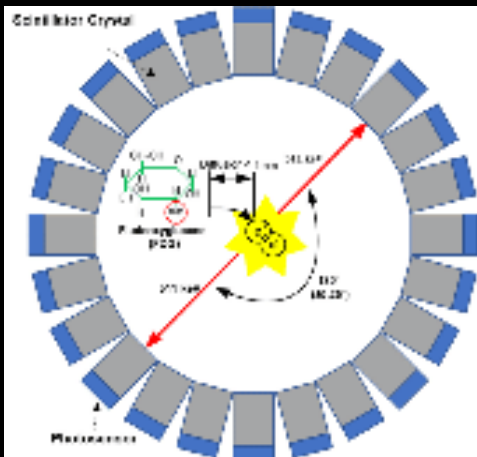
$$i\hbar\gamma^\mu\partial_\mu\psi(x) - m\psi(x) = 0$$

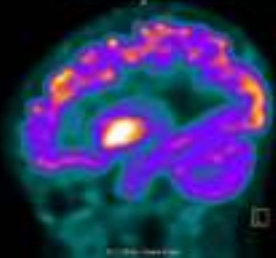
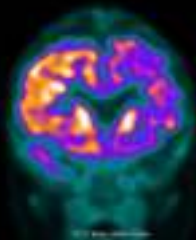






Andy Warhol





$$N = N_0 e^{-t/\tau}$$

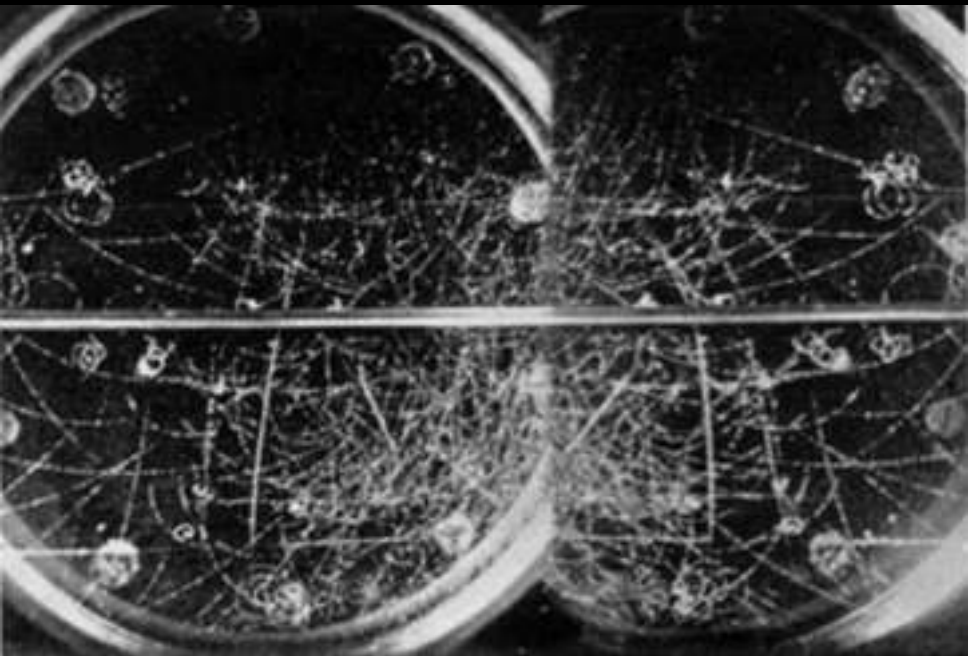
$$\tau = 2.2 \mu\text{s}$$

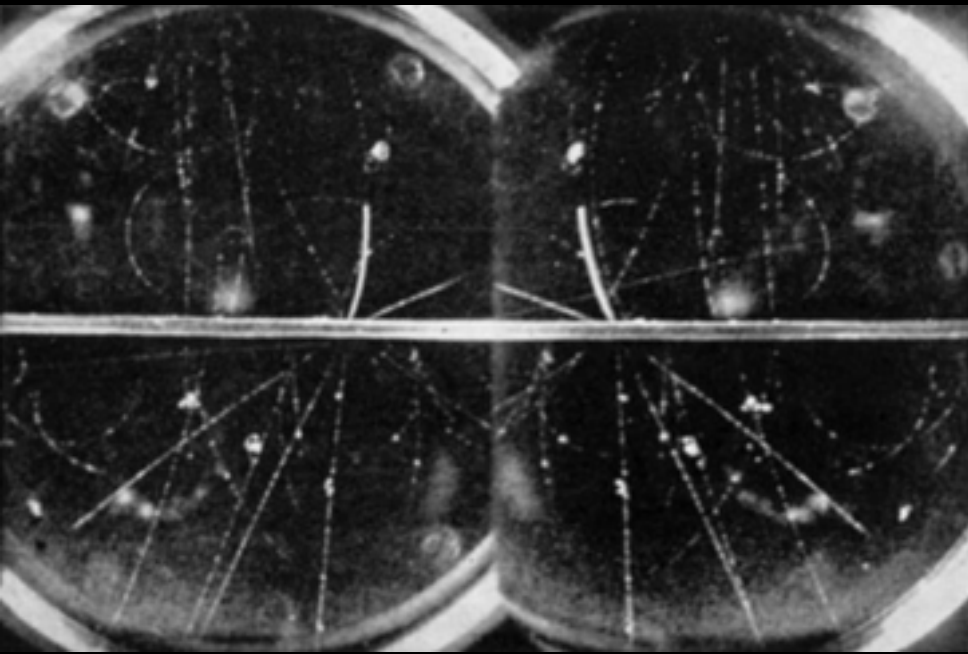
$$v = 99.5\%c$$

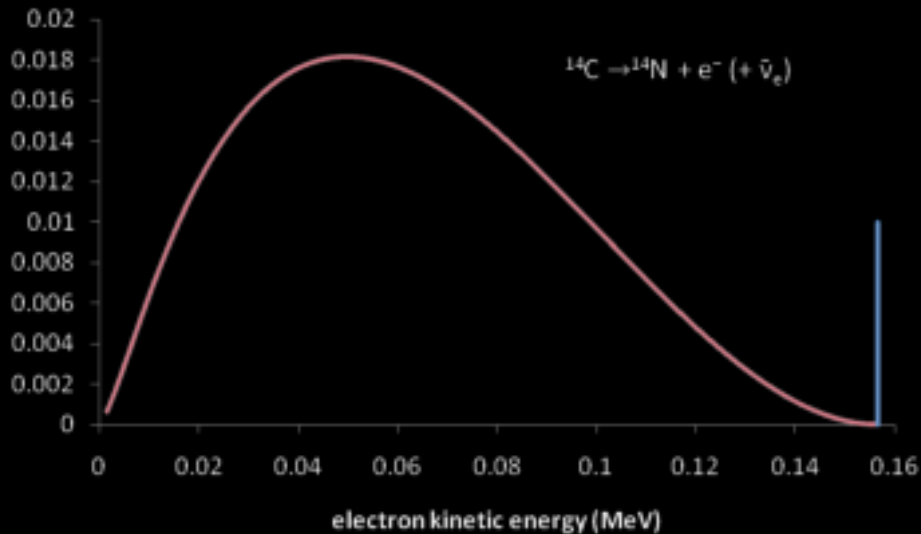
$$d = \tau \cdot v \simeq 2.2 \cdot 10^{-6} \text{s} \cdot 0.995 \cdot 3 \cdot 10^8 \text{m/s} = 660 \text{m}$$

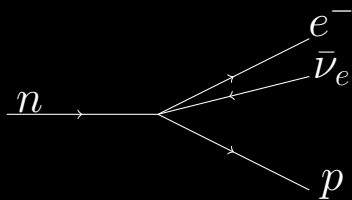
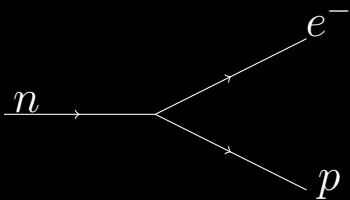
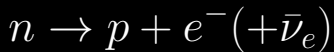
$$d' = \frac{d}{\sqrt{1 - \frac{v^2}{c^2}}} \simeq 10 \cdot d = 6600 \text{m}$$

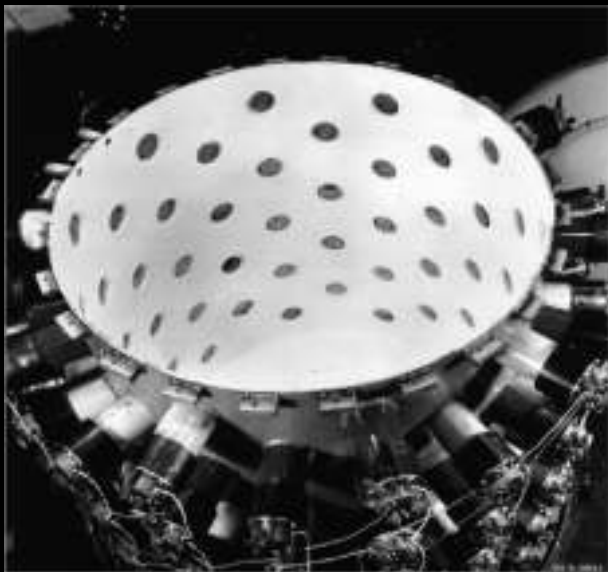
$$\tau' = \tau \sqrt{1 - \frac{v^2}{c^2}} \simeq 10 \cdot \tau = 22 \mu\text{s}$$











Detection of the Free Neutrino*

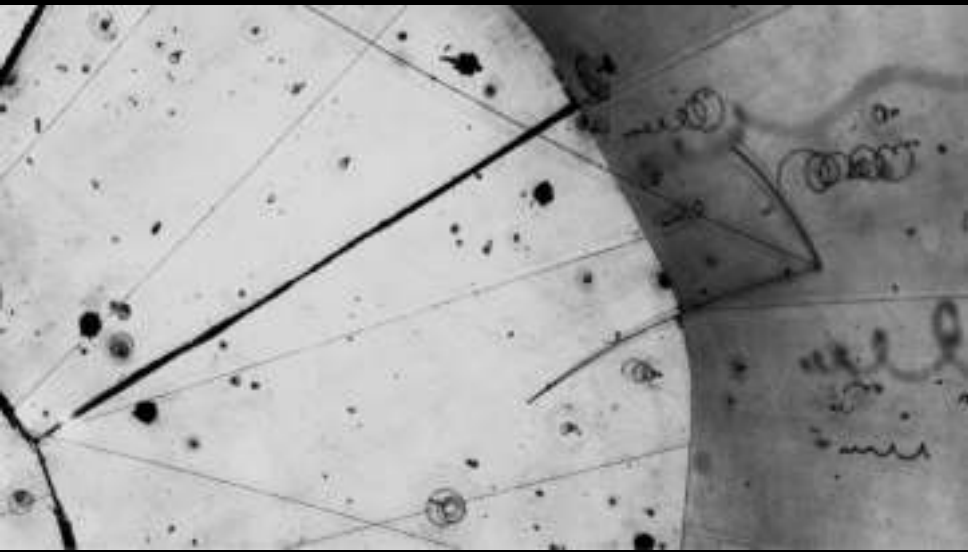
F. REINES AND C. L. COWAN, JR.

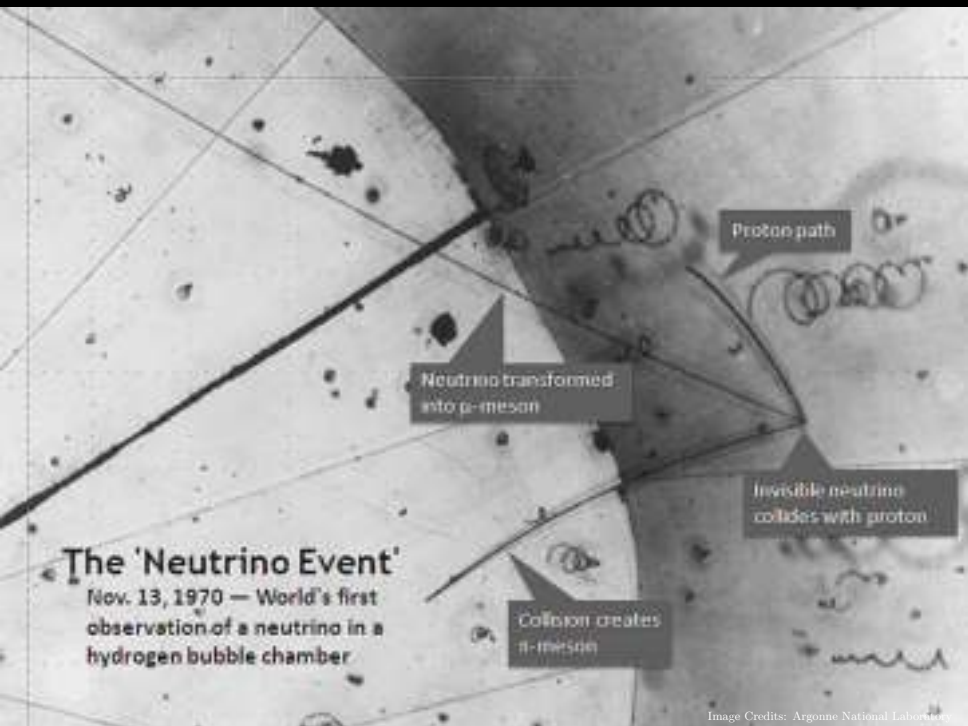
*Los Alamos Scientific Laboratory, University of California,
Los Alamos, New Mexico*

(Received July 9, 1953; revised manuscript received September 14, 1953)

AN experiment¹ has been performed to detect the free neutrino. It appears probable that this aim has been accomplished although further confirmatory work is in progress. The cross section for the reaction employed,

$$\nu_{-} + p \rightarrow n + \beta^{+}, \quad (1)$$





Proton path

Neutrino transformed into μ -meson

Invisible neutrino collides with proton

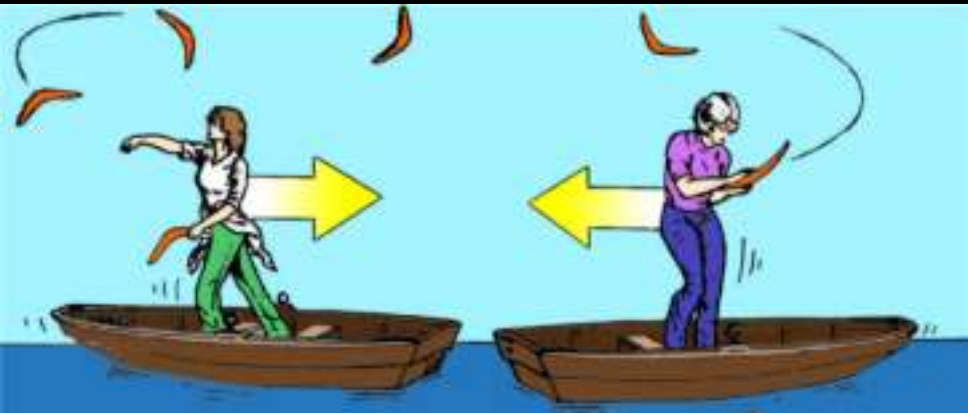
Collision creates π -meson

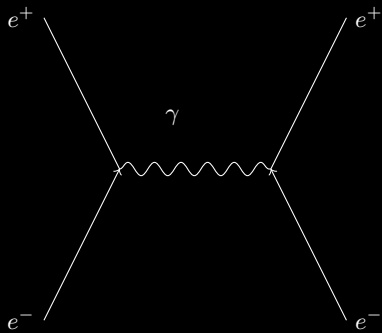
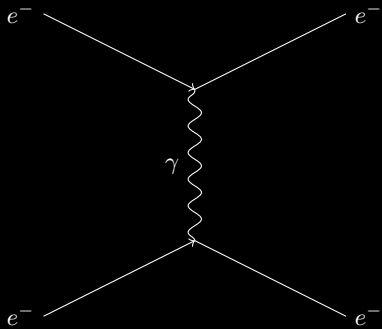
The 'Neutrino Event'
Nov. 13, 1970 — World's first observation of a neutrino in a hydrogen bubble chamber

$$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$$

$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$$





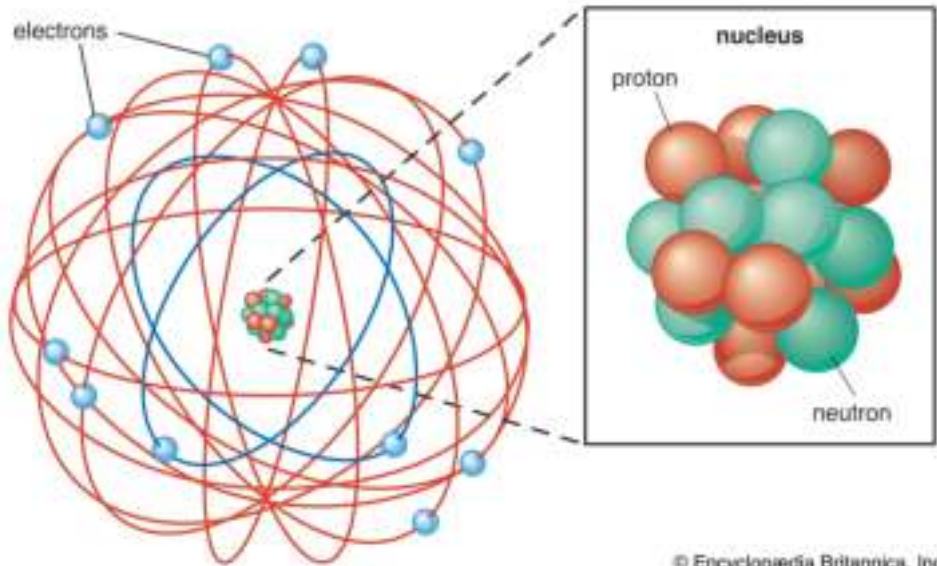


$$S = 4\pi r^2$$

$$n = \frac{N}{4\pi r^2}$$

$$F \propto \frac{1}{r^2}$$

$$F = \frac{GmM}{r^2} \quad F = k\frac{qQ}{r^2}$$

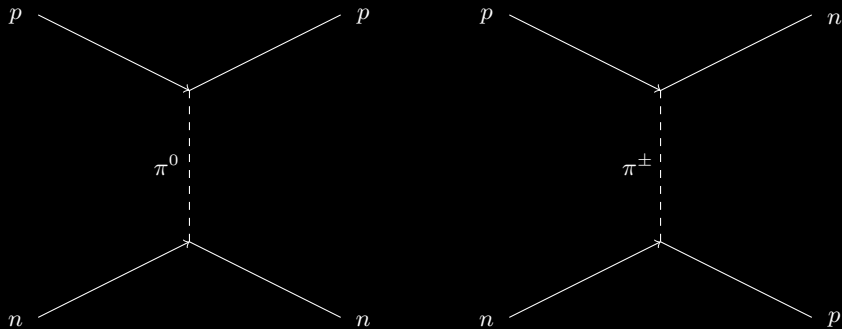


Principio di indeterminazione *Di uno stato quantistico non possiamo misurare con precisione arbitraria tutte le grandezze simultaneamente.*

Se conosciamo con alta precisione l'impulso allora non conosciamo la posizione e come abbiamo detto prima la particella è delocalizzata. Viceversa se si può conoscere la posizione non se ne conosce l'impulso, quindi la velocità.

$$\Delta x \Delta p > \hbar$$

$$\Delta E \Delta t > \hbar$$



$$F \propto \frac{e^{-\lambda r}}{r^2}$$



Fig. 1.

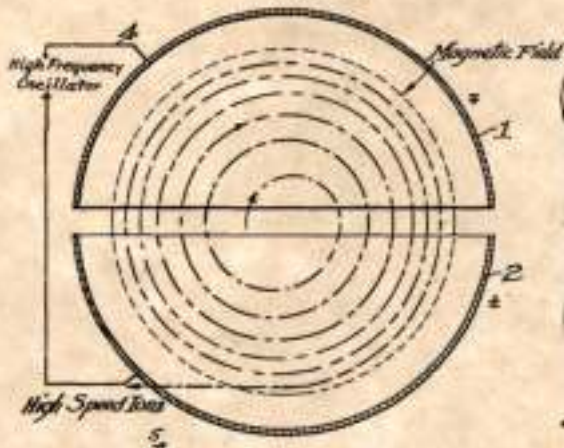
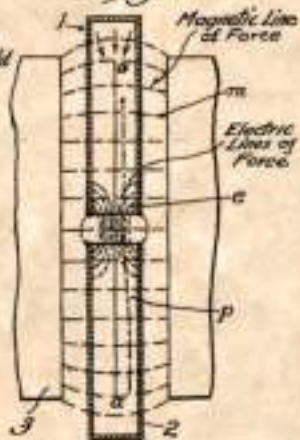


Fig. 2.





e^-, ν, μ^-

$n, p,$

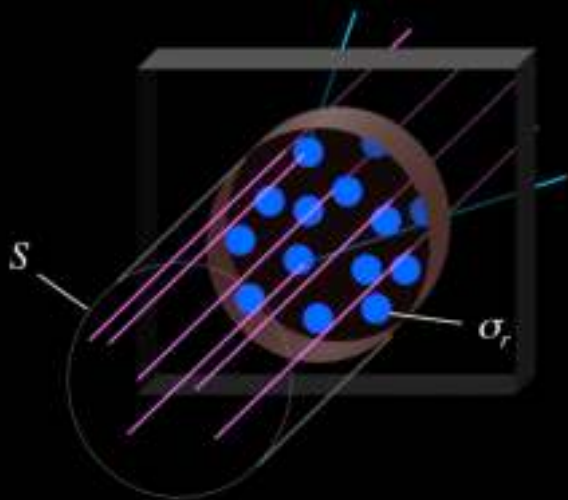
$\pi^+, \pi^0,$

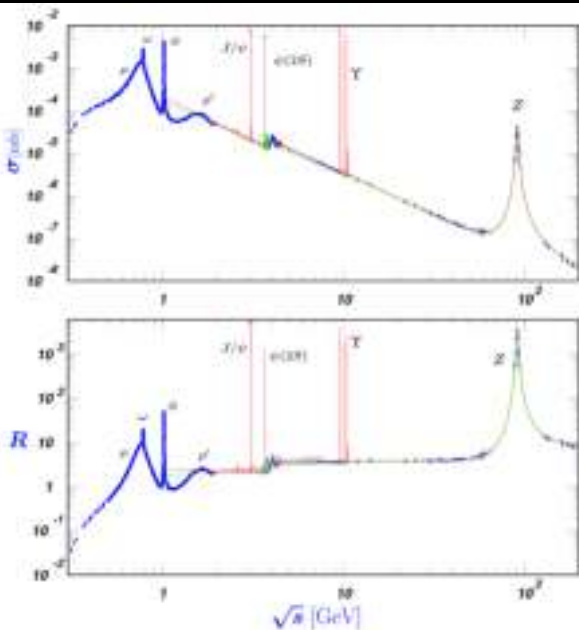
$\Delta^+, \Delta^+, \Delta^0,$

$\Sigma^0, \Sigma^+, \Lambda^0,$

K^+, K^0

Ξ^+, Ξ^0, \dots





$$p + p \rightarrow n + p + \pi^+$$

$$p + p \rightarrow n + \Delta^{++} \rightarrow n + p + \pi^+$$

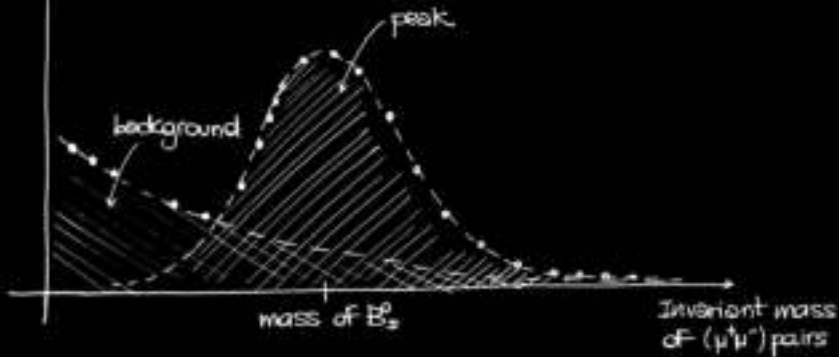
$$E = E_1 + E_2$$

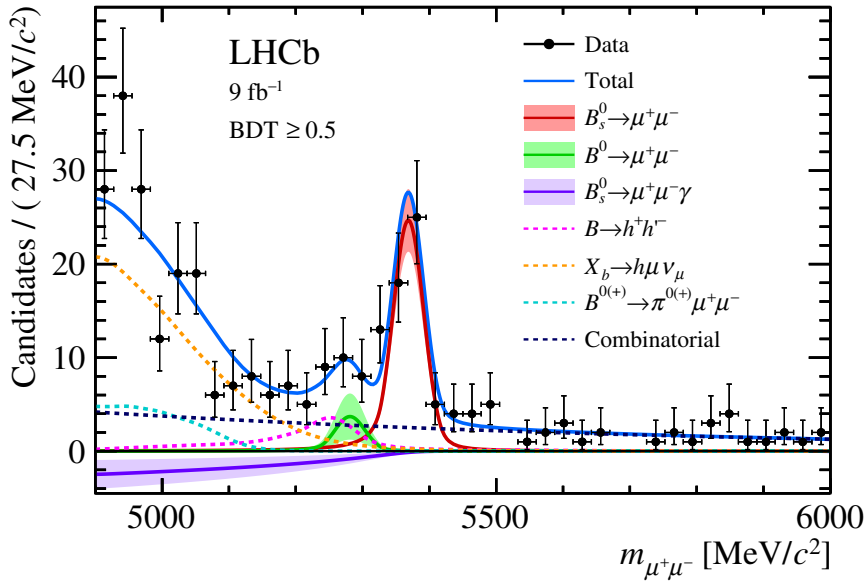
$$p = p_1 + p_2$$

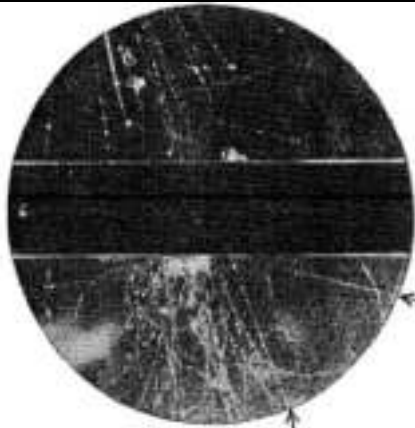
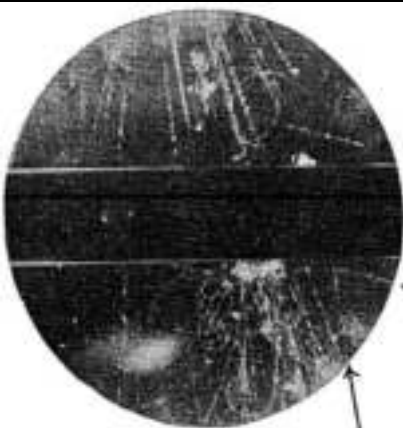
$$E = \sqrt{m^2 c^4 + p^2 c^2}$$

$$m = \sqrt{E^2 - p^2 c^2} / c^2$$

• distribution of candidates

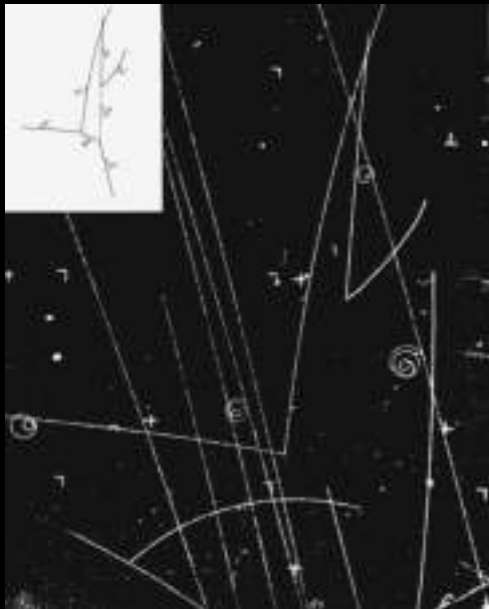


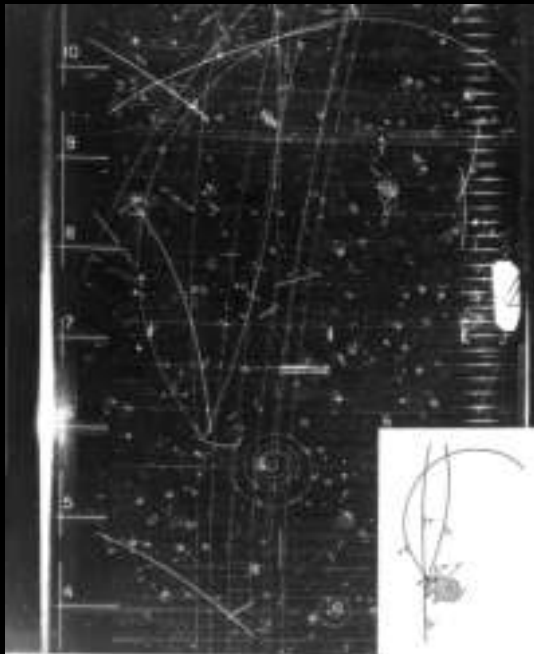




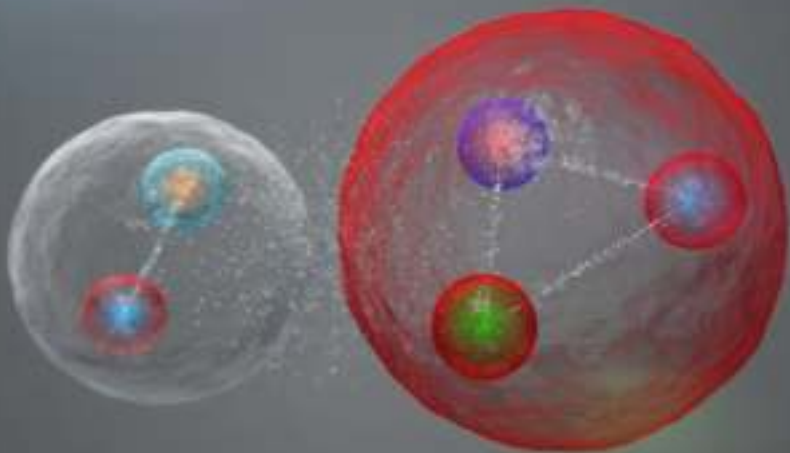


Production and decay of neutral lambda and anti-lambda hyperons

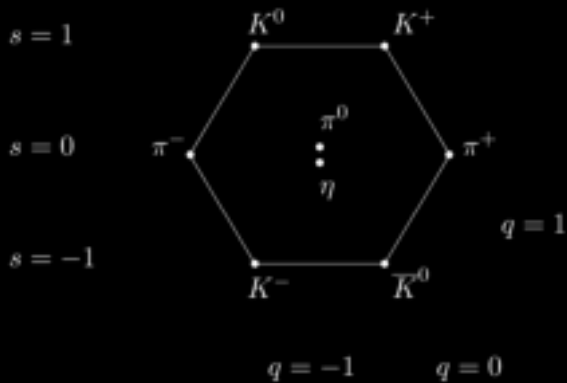


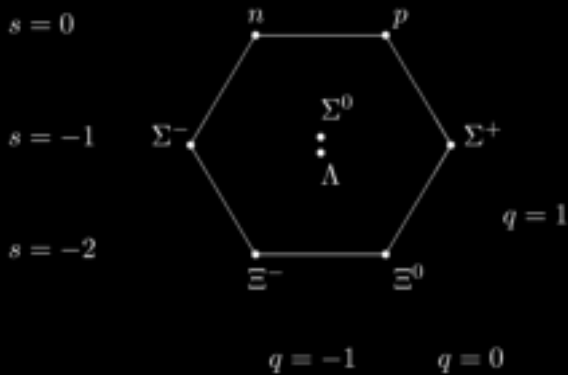


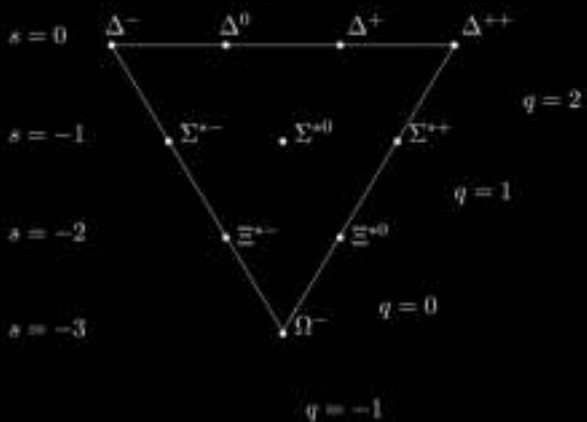
Production and decay of a xi zero

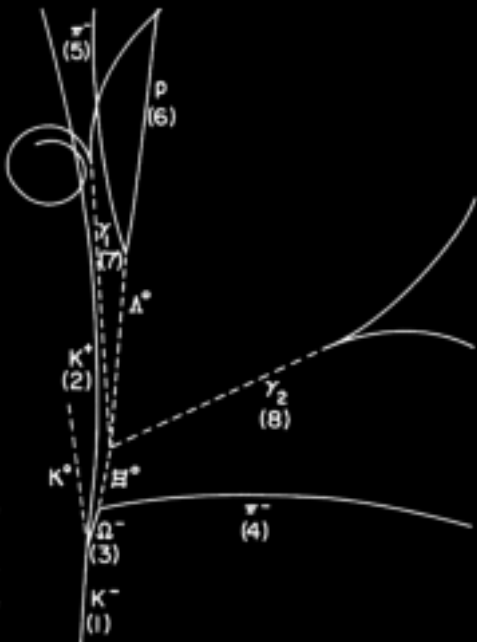
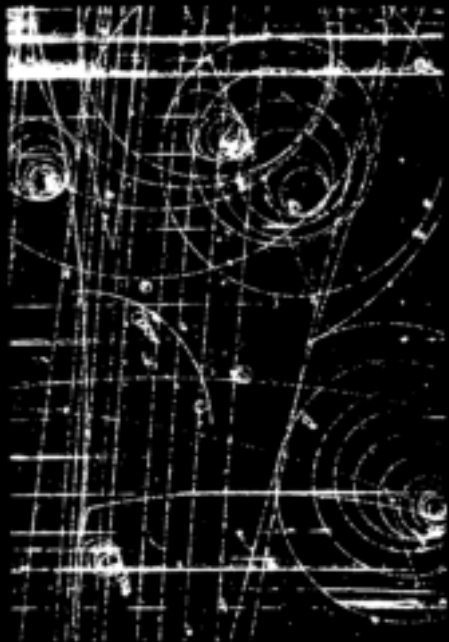


	Fermioni	Bosoni
	Spin 1/2 ...	Spin 0, 1 ...
	Leptoni	Adroni
		Barioni
	e, μ, ν	Mesoni
Strani	$p, n,$ Λ, Σ, \dots	π, π^0 K, K^0





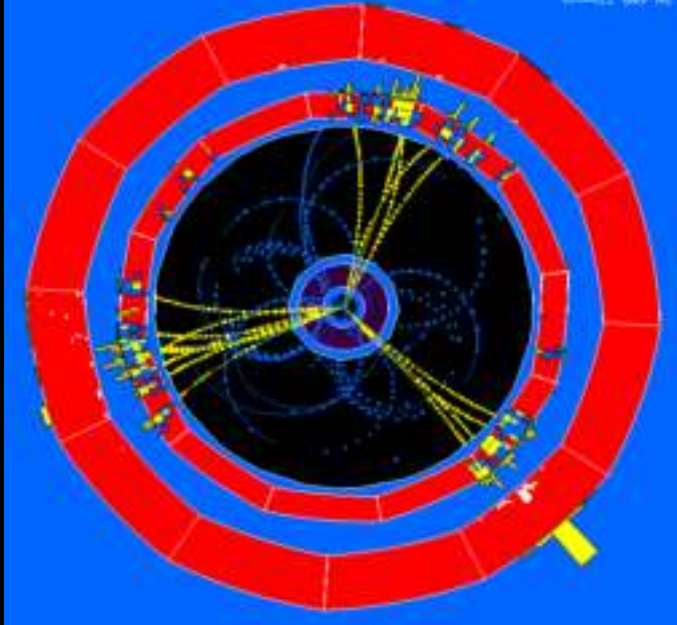








$$\lambda = \frac{h}{p}$$

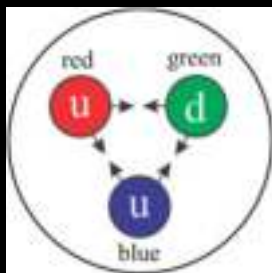




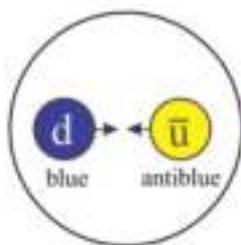
Quark	Carica	Spin
u	$+2/3$	$1/2$
d	$-1/3$	$1/2$
s	$-1/3$	$1/2$
\bar{u}	$-2/3$	$1/2$
\bar{d}	$+1/3$	$1/2$
\bar{s}	$+1/3$	$1/2$

Particella	Carica	Spin	Quark
p	+1	1/2	uud
\bar{p}	-1	1/2	$\bar{u}\bar{u}\bar{d}$
n	0	1/2	udd
\bar{n}	0	1/2	$\bar{u}\bar{d}\bar{d}$
π^+	+1	0	$u\bar{d}$
π^-	-1	0	$\bar{u}d$
π^0	0	0	$u\bar{u} + d\bar{d}$
ρ^+	+1	+1	$u\bar{d}$
Δ^{++}	+2	3/2	uuu
Δ^+	+1	3/2	uud
Δ^0	0	3/2	udd

Particella	Carica	Spin	Quark
Λ^0	0	1/2	uds
Σ^0	0	1/2	uds
Σ^+	1	1/2	uus
Σ^-	-1	1/2	dds
K^+	+1	0	$u\bar{s}$
K^0	0	0	$d\bar{s}$
\bar{K}^0	0	0	$s\bar{d}$
Ξ^-	-1	1/2	ssd
Ξ^0	0	1/2	uss
Ω^-	-1	1/2	sss

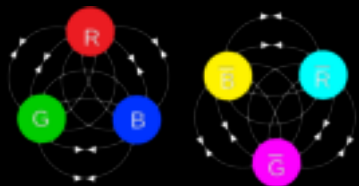


Baryon
(proton, p^+)

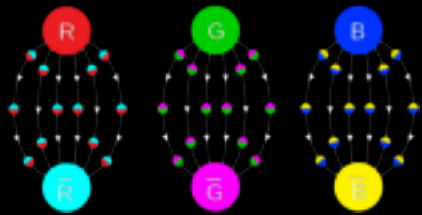


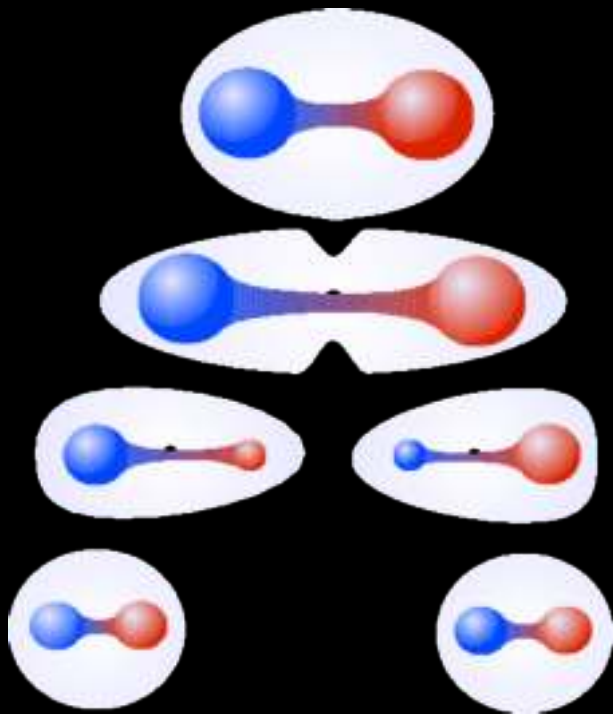
Meson
(negative pion, π^-)

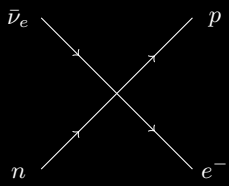
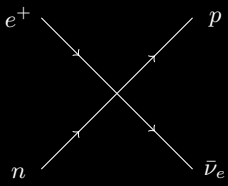
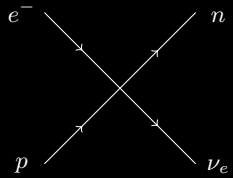
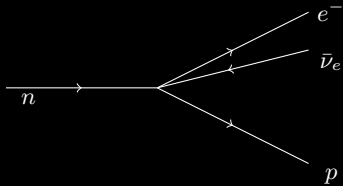
Barioni



Mesoni





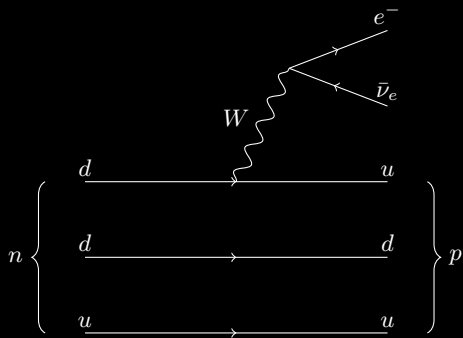


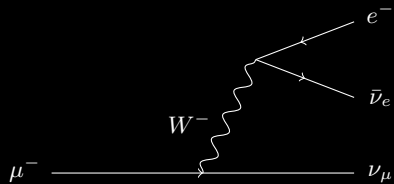
$$F = \mathbf{G} \frac{mM}{r^2}$$

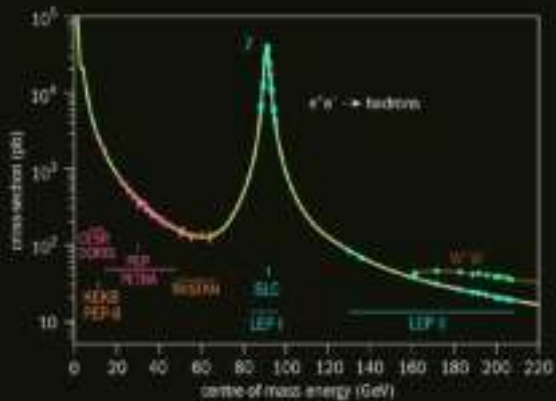
$$F = \mathbf{k} \frac{qQ}{r^2}$$

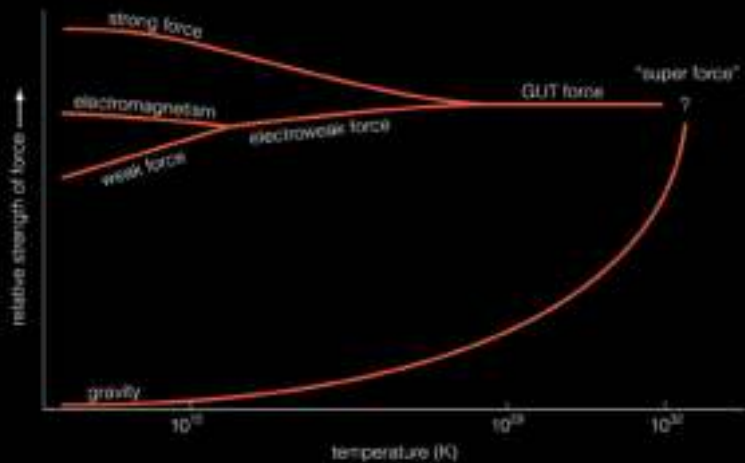
$$F \propto \mathbf{g} \frac{e^{-\lambda r}}{r^2}$$

$$F \propto \mathbf{G}_F \quad ? \quad F \propto \mathbf{k} e^{-\omega r}$$

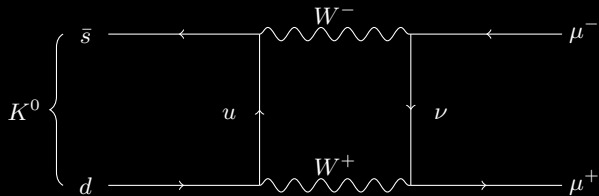




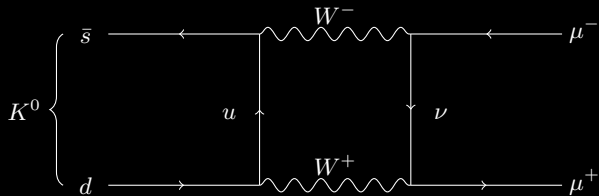




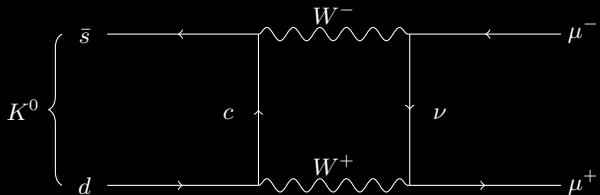
$$K^0 \rightarrow \mu^+ \mu^-$$



$$K^0 \rightarrow \mu^+ \mu^-$$

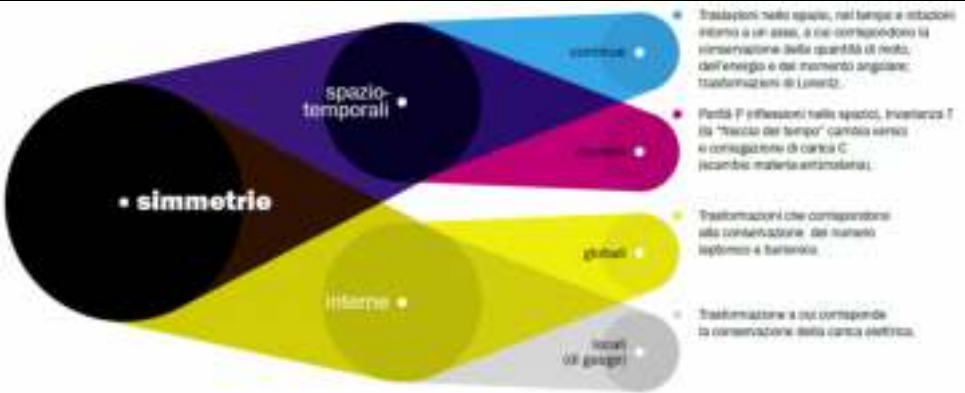


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Simmetria	Proprietà	Quantità conservata
Traslazione nello spazio	Omogeneità dello spazio	Quantità di moto
Rotazione nello spazio	Isotropia dello spazio	Momento angolare
Traslazione nel tempo	Omogeneità del tempo	Energia

CPT
(Inversione di)
Carica Parità Tempo

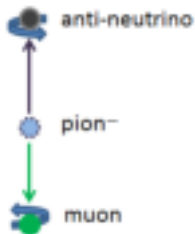
ALLOWED



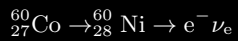
NOT ALLOWED

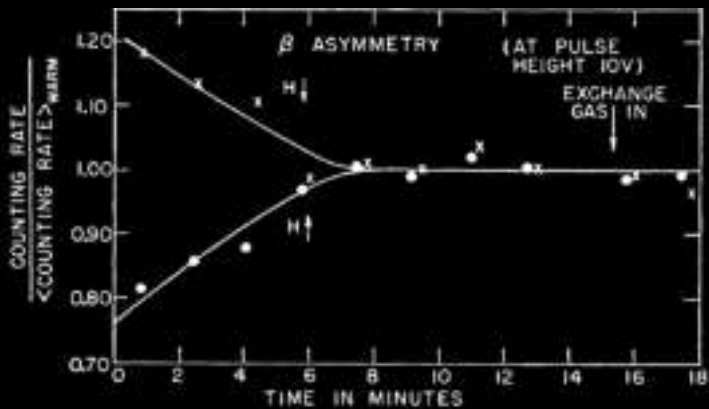


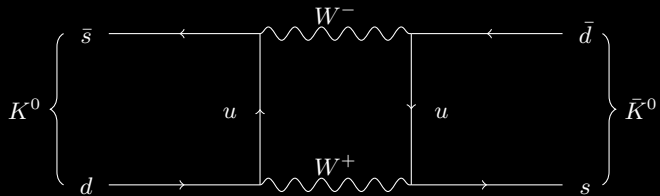
ALLOWED

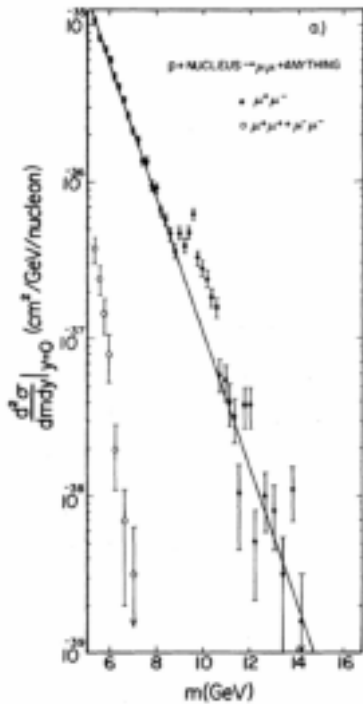


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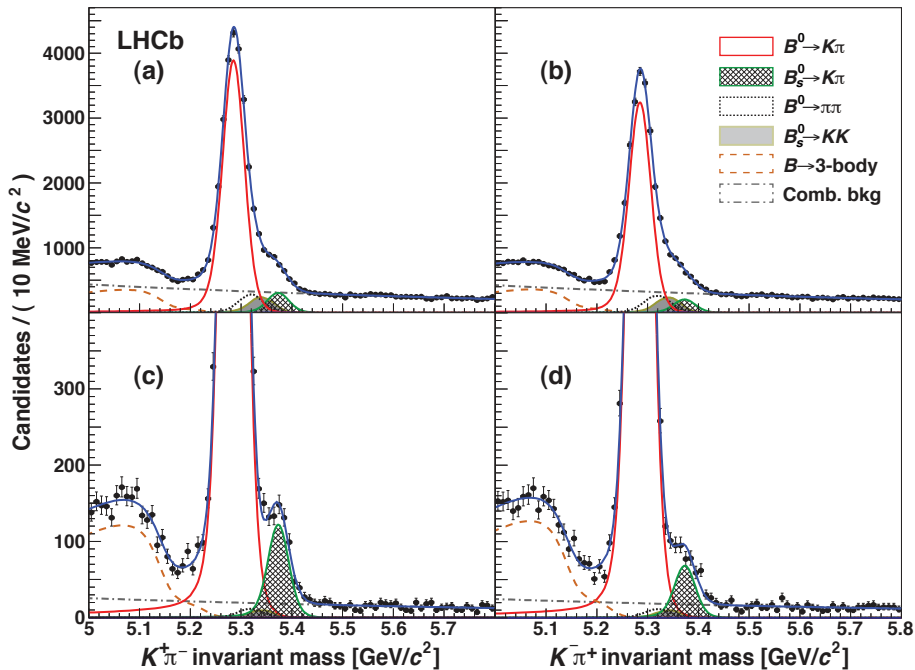






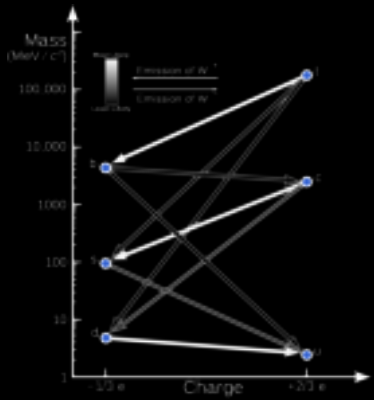
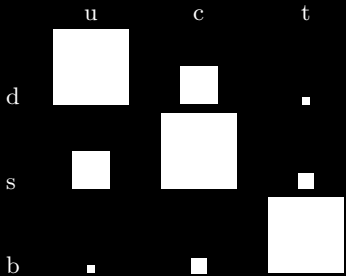


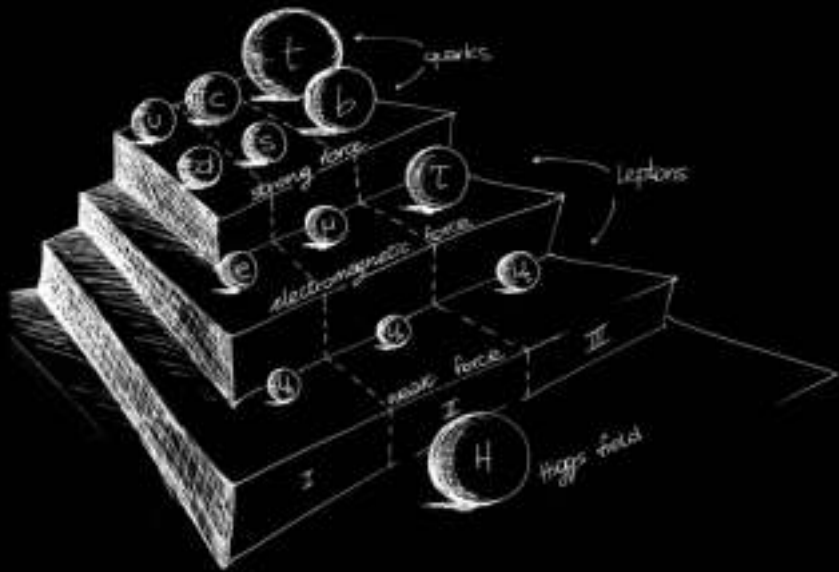


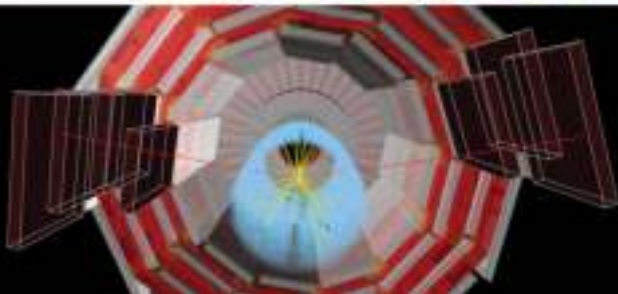
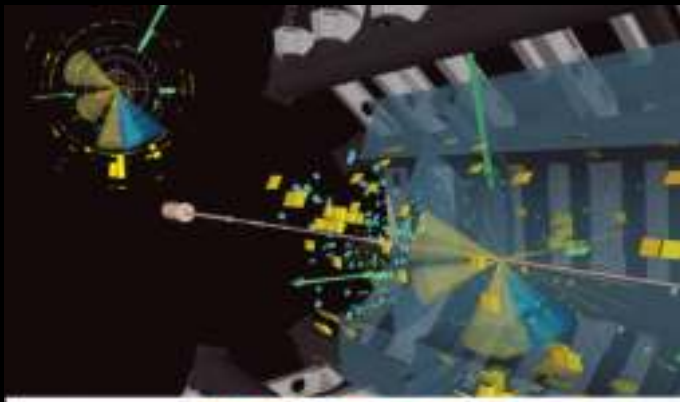


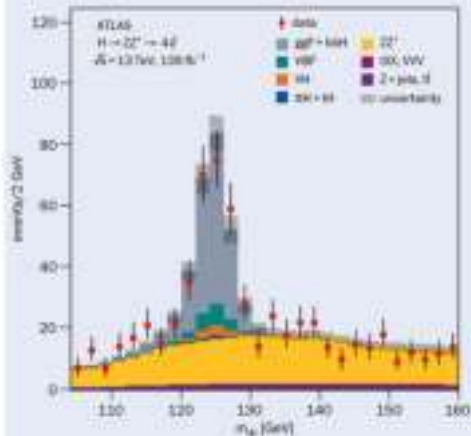
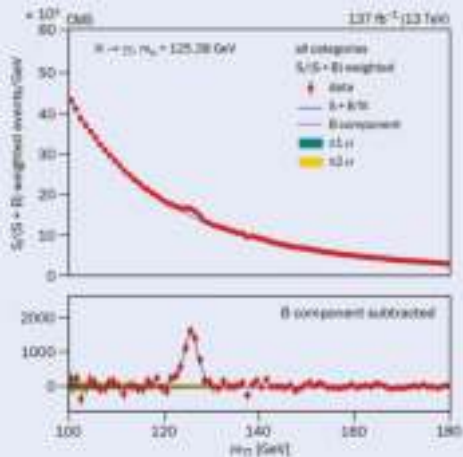


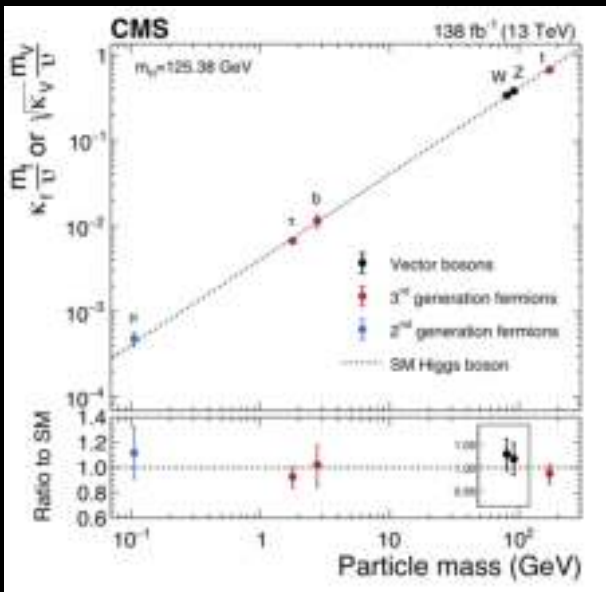
Three Generations of Matter













$$\begin{aligned}\mathcal{L} = & -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\ & + i\bar{\psi}\not{D}\psi + h.c. \\ & + \chi_i y_{ij} \chi_j \phi + h.c. \\ & + |\partial_\mu \phi|^2 - V(\phi)\end{aligned}$$

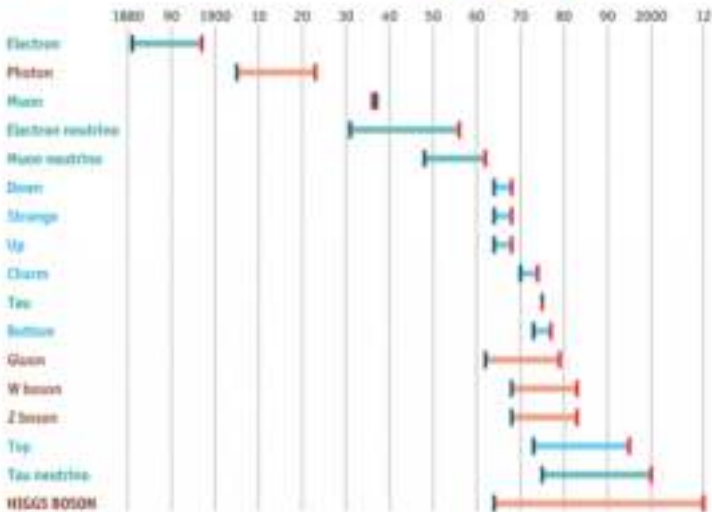




The Standard Model of particle physics

Years from concept to discovery

Legend:
Leptons (teal)
Bosons (orange)
Quarks (blue)
Theories/Explained (black vertical bar)
Discovered (red vertical bar)

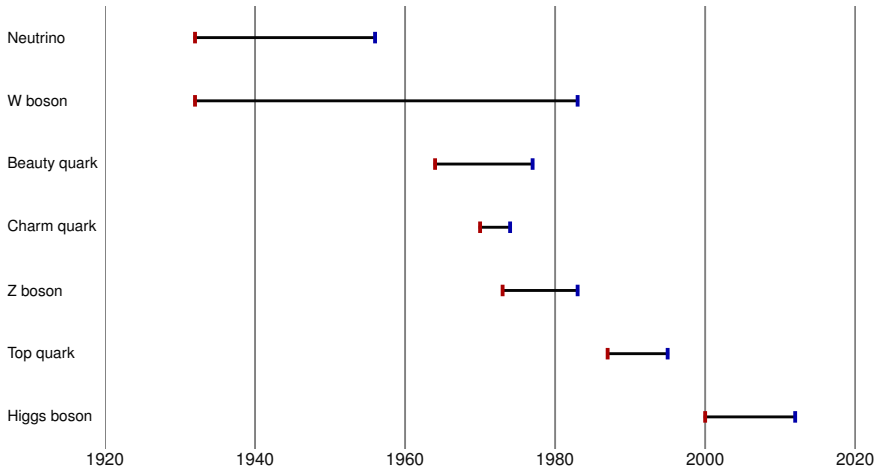


Source: The Economist

The Standard Model of particle physics

Years from indirect to direct observation of new particles

■ Indirect
■ Direct



The end?