Chiedere alla polvere
Introduzione alla Fisica delle particelle elementari

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Università degli Studi di Cagliari

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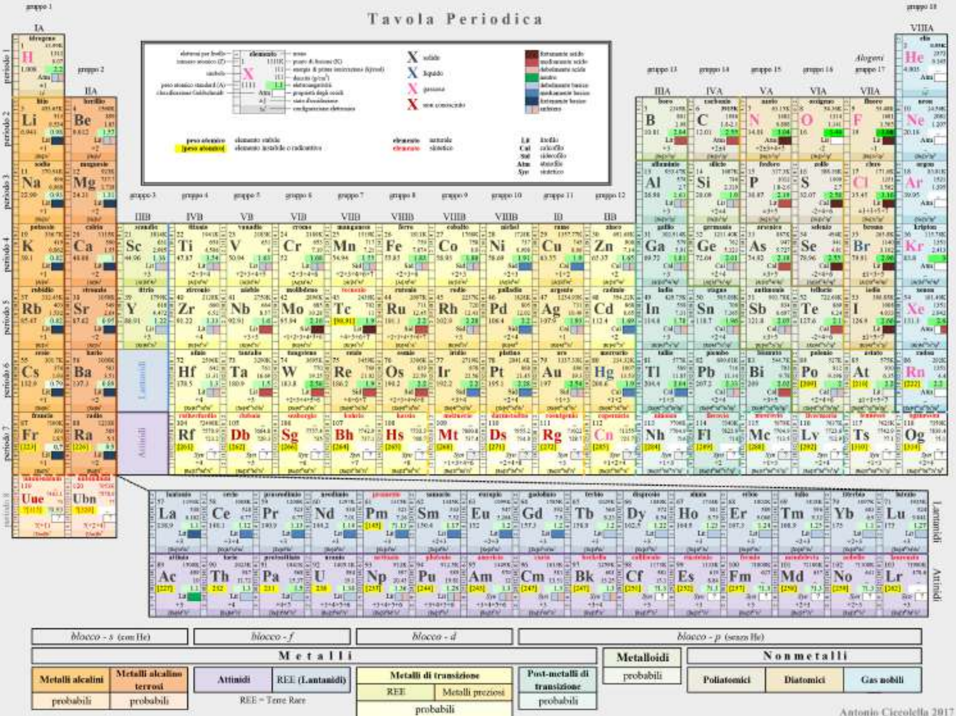
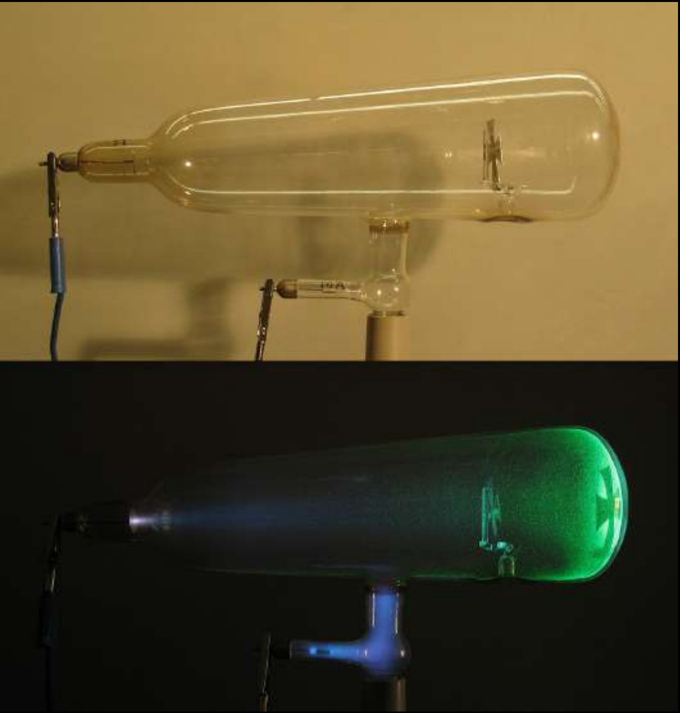
Tavola Periodica





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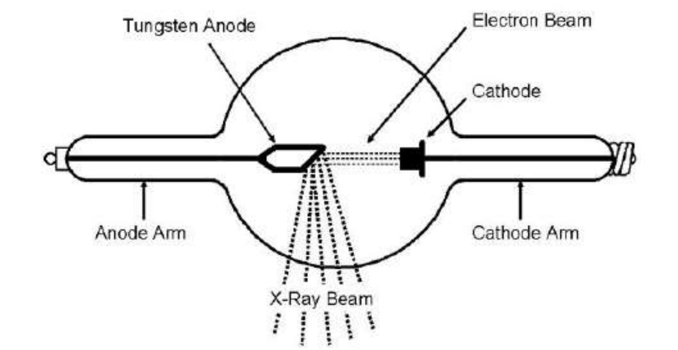
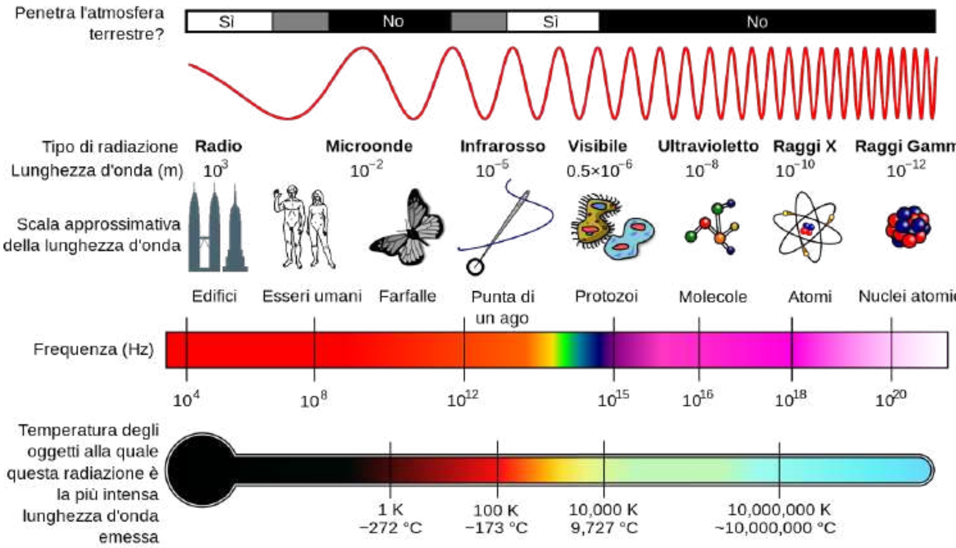

Tungsten Anode
Electron Beam
Cathode
Anode Arm
Cathode Arm
X-Ray Beam

Image Credits: Radiopaedia



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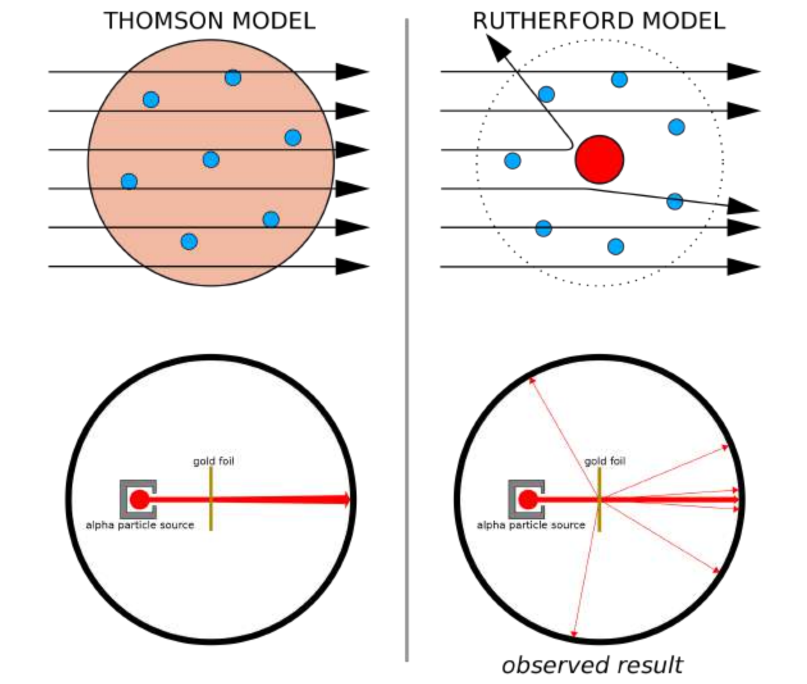

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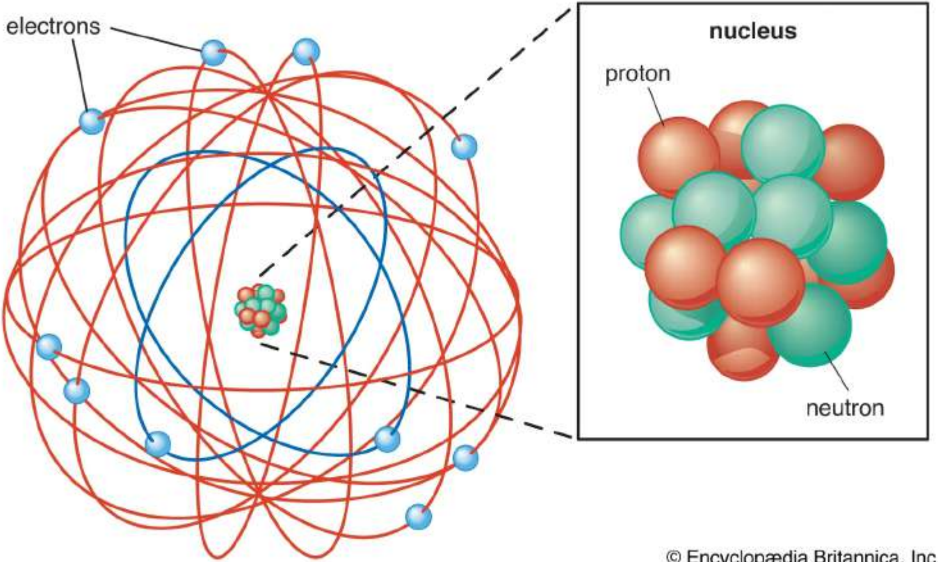
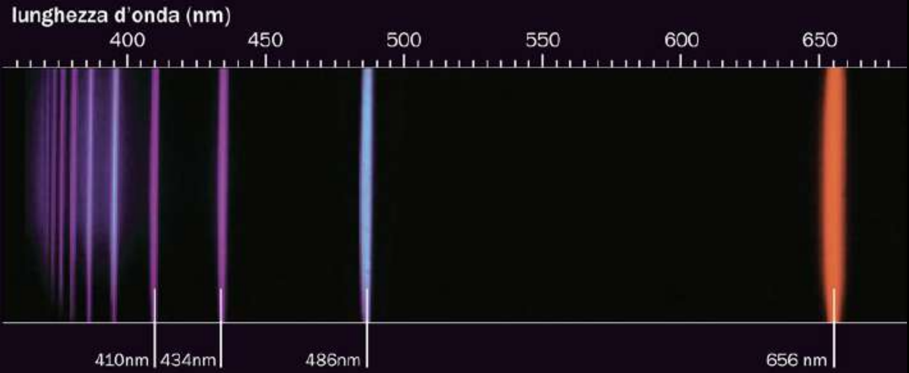
$$E = \frac{1}{2}mv^2 \qquad E = k\frac{qQ}{r}$$

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


electrons
nucleus
proton
neutron

$$E = h\nu$$



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

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

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

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

$$E = h\nu = pc$$

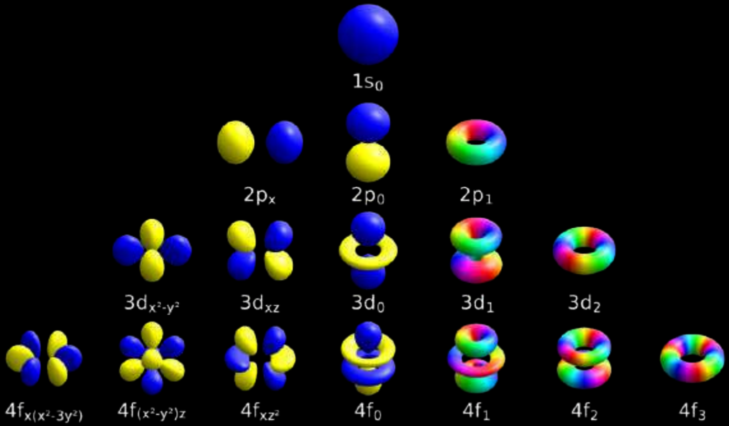
$$p = \frac{h\nu}{c} = \frac{h}{\lambda} \qquad \Rightarrow \lambda = \frac{h}{p}$$

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

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

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

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



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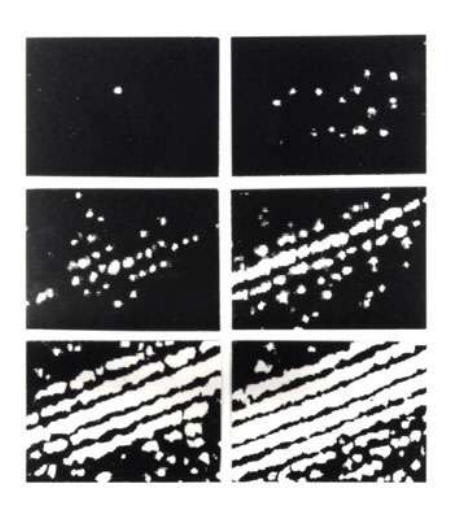

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$$^{14}_{7}\mathrm{N} + \alpha \rightarrow {}^{17}_{8}\mathrm{O} + \mathrm{H}$$

Neutronografia di una caffettiera
https://www.youtube.com/watch?v=VESMU7JfVHU

$\alpha \qquad \beta \qquad \gamma$

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

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

Image Credits: Museo Galileo

Image Credits: Wikipedia

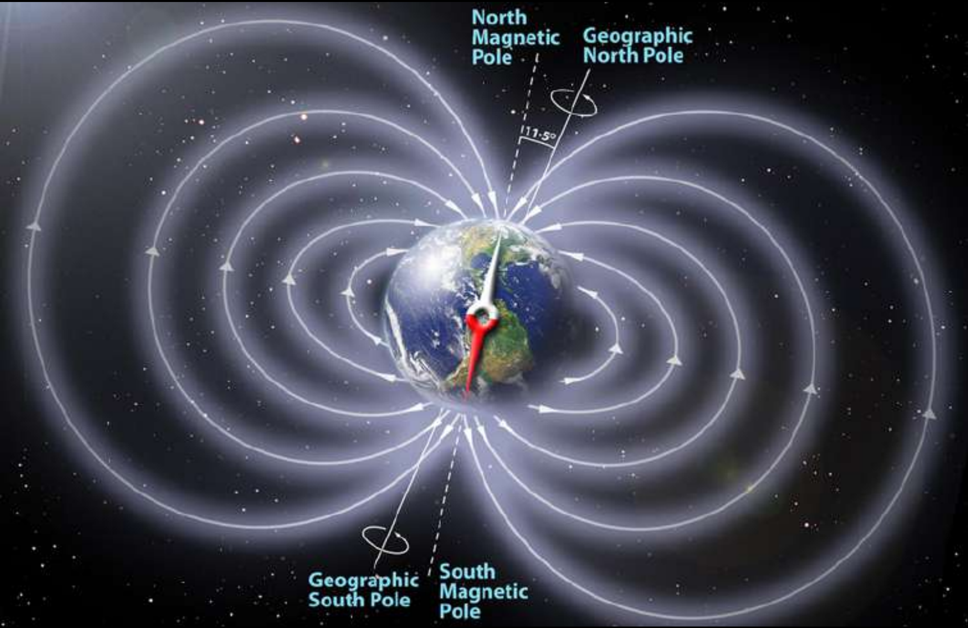


Image Credits: Wikipedia


Image Credits: Brantley Lake State Park

$$E = h\nu$$

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

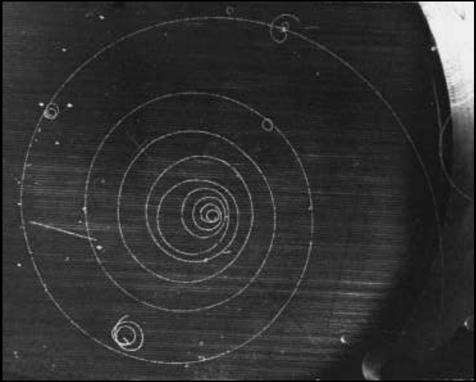
$$i\hbar\gamma^{\mu}\partial_{\mu}\psi(x) - m\psi(x) = 0$$

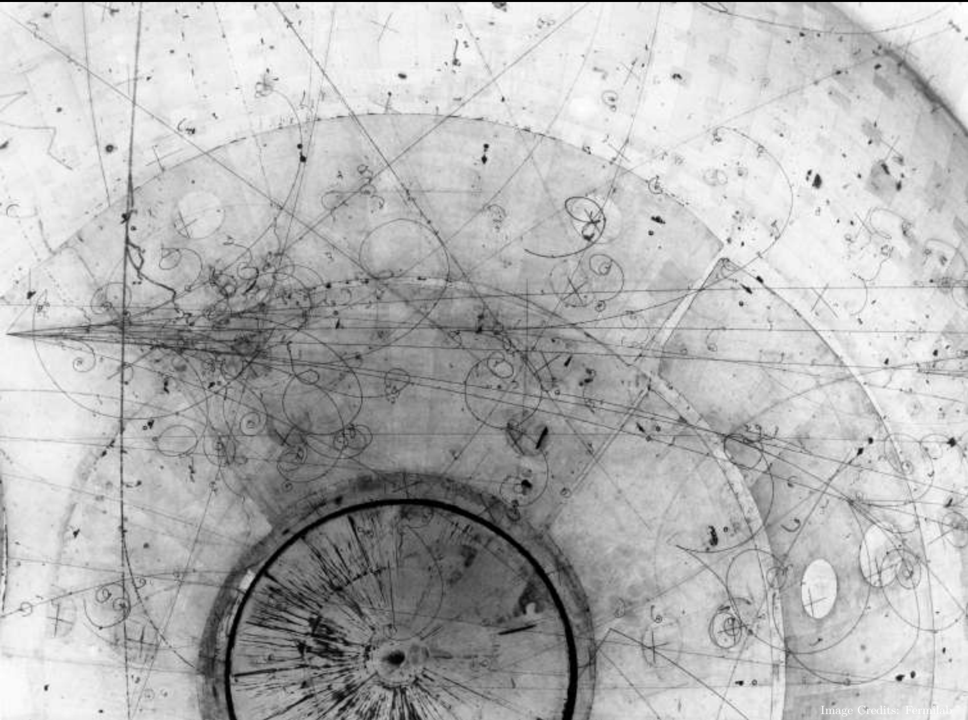
Camera a Nebbia

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

$$F = ma = m\frac{v^2}{R} \qquad \vec{F} = e\vec{v} \times \vec{B}$$

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





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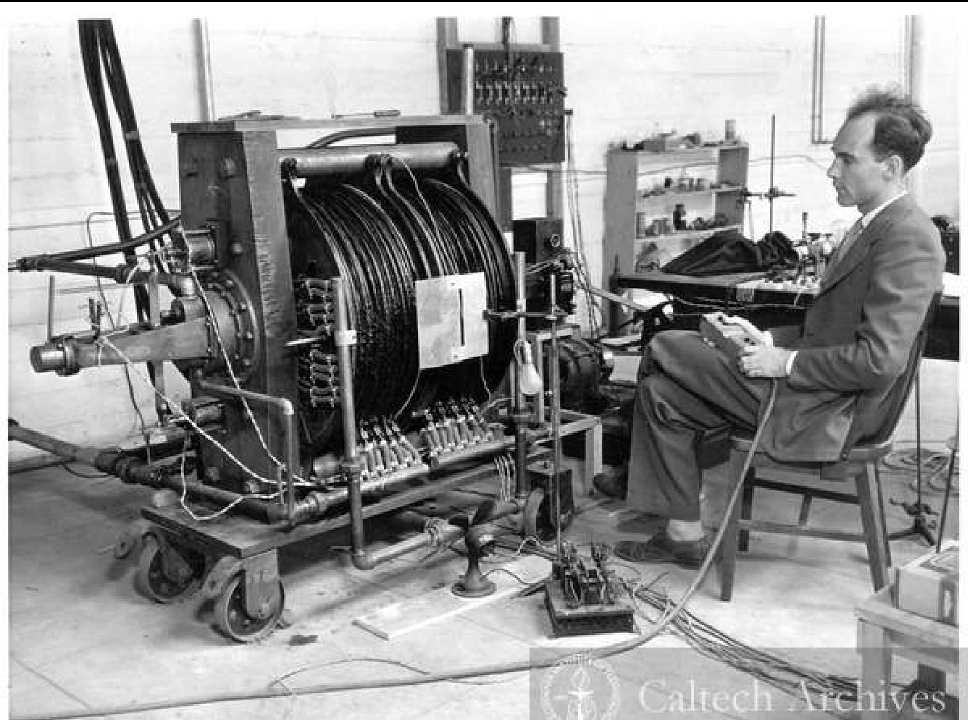

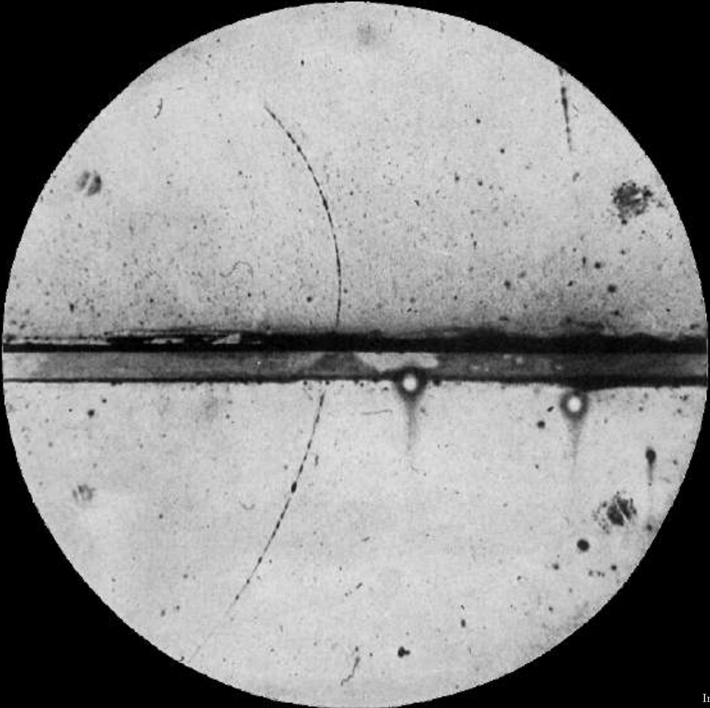

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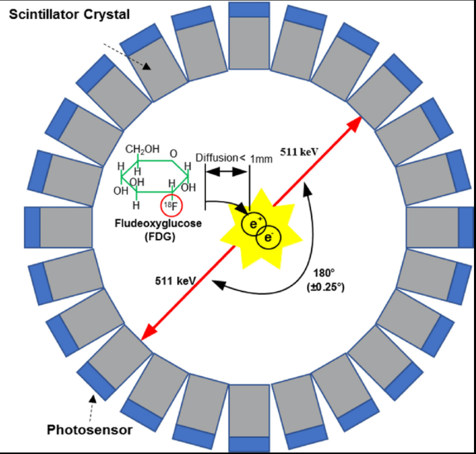

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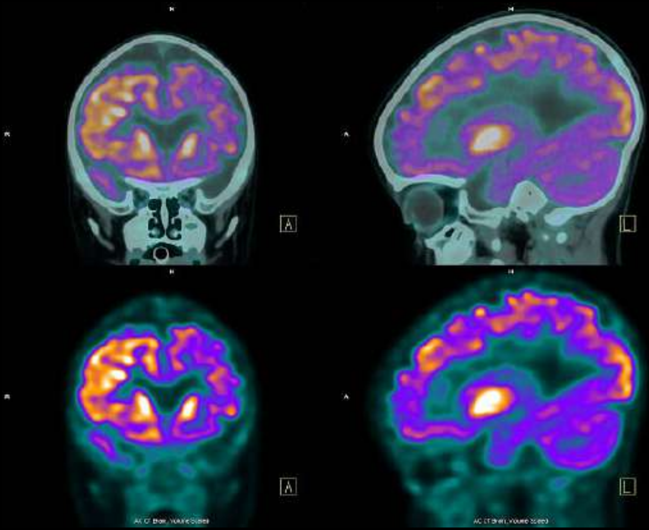


Image Credits: radiologyinfo.org

$$dN \propto -N dt$$

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

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

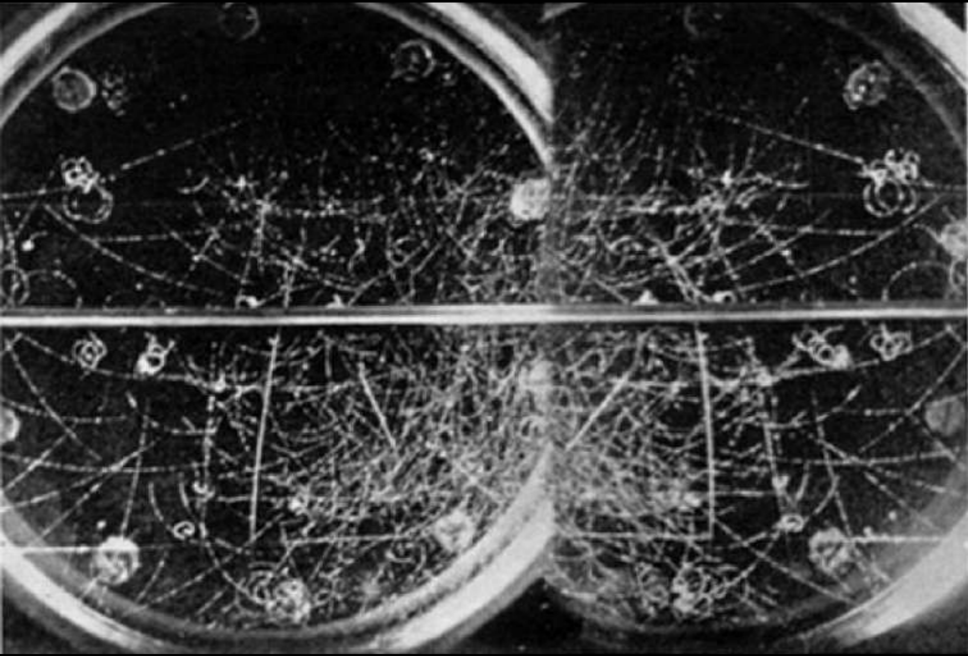
$$\tau = 2.2\mu s$$

$$v = 99.5\% c$$

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

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

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



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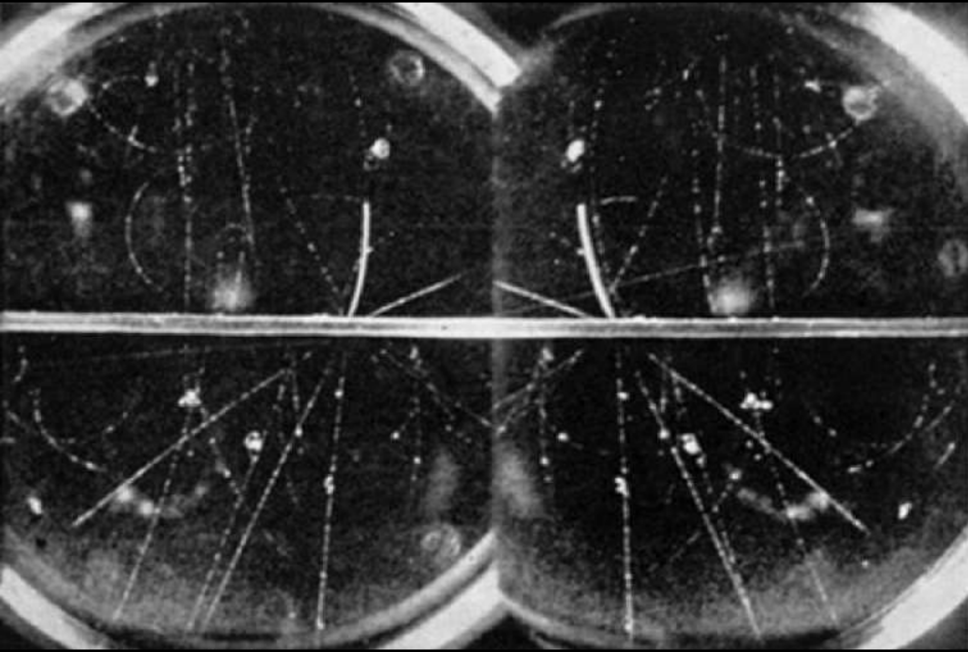

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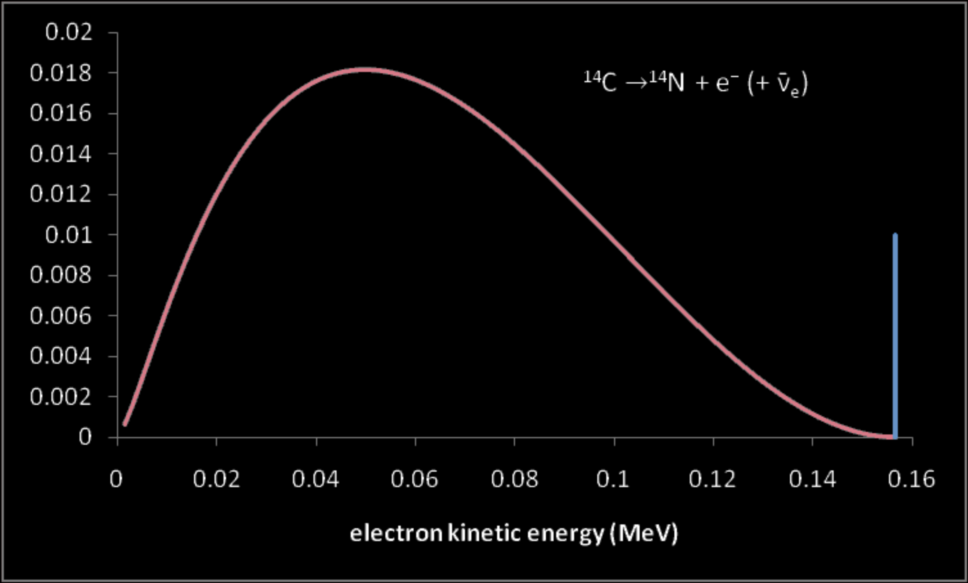
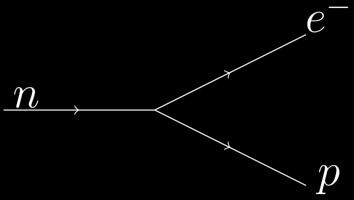
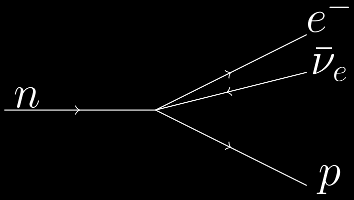


0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
$^{14}C \rightarrow ^{14}N + e^- (+ \bar{\nu}_e)$
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
electron kinetic energy (MeV)

$$^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + \mathrm{e}^{-}(+\bar{\nu}_{\mathrm{e}})$$

$$n \rightarrow p + e^{-}(+\bar{\nu}_{e})$$





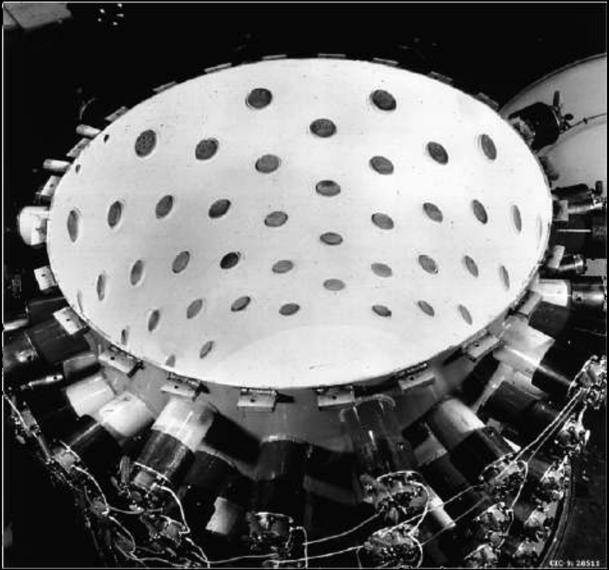


Image Credits: Washington University

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 experiment[1] 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,

$$\nu_- + p \rightarrow n + \beta^+, \tag{1}$$

Image Credits: Physical Review

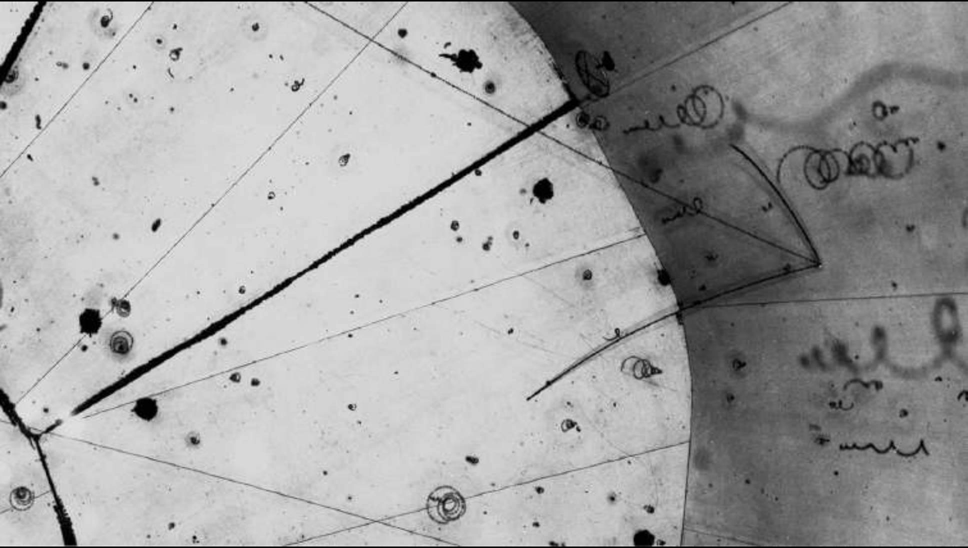
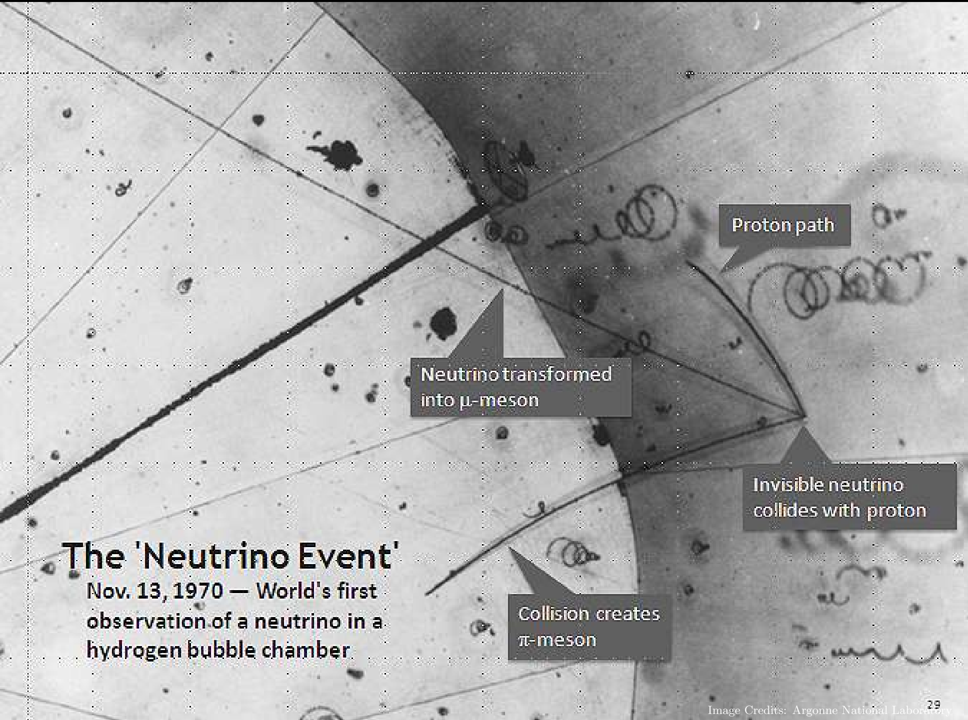


Image Credits: Argonne National Laboratory



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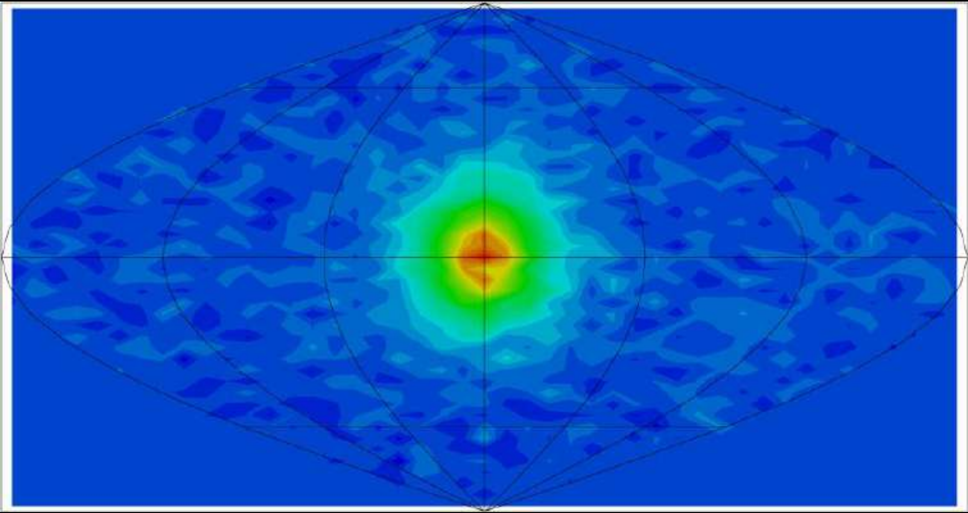


Image Credits: Superkamiokande

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

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

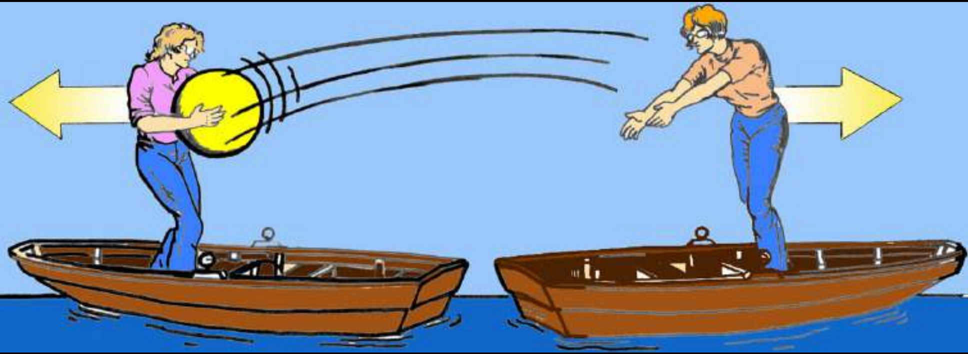
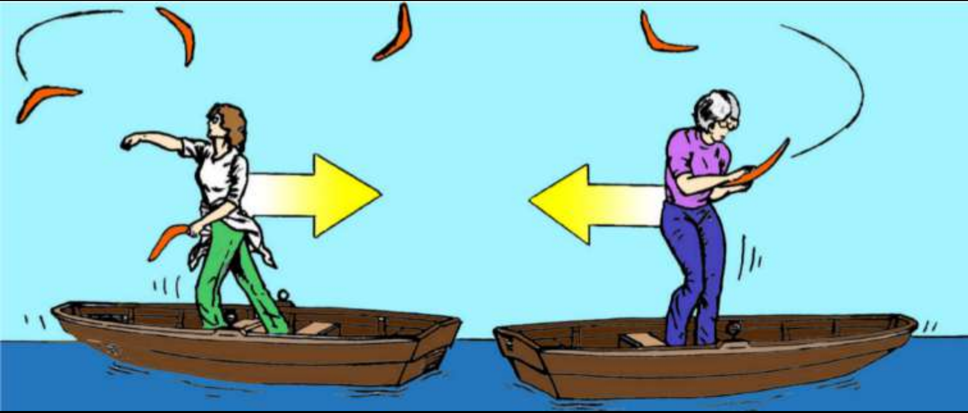


Image Credits: Fermilab



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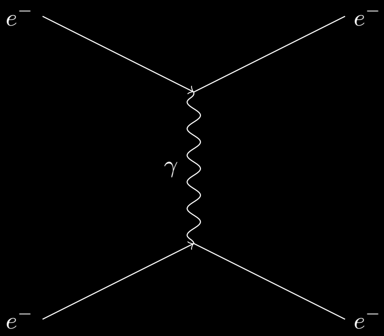
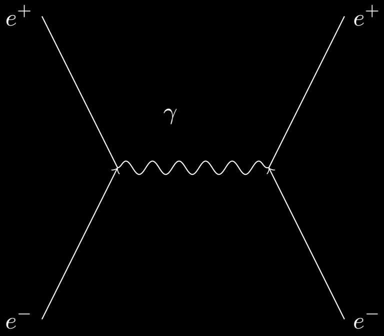

e^-
e^-
γ
e^-
e^-


e^+
e^+
γ
e^-
e^-

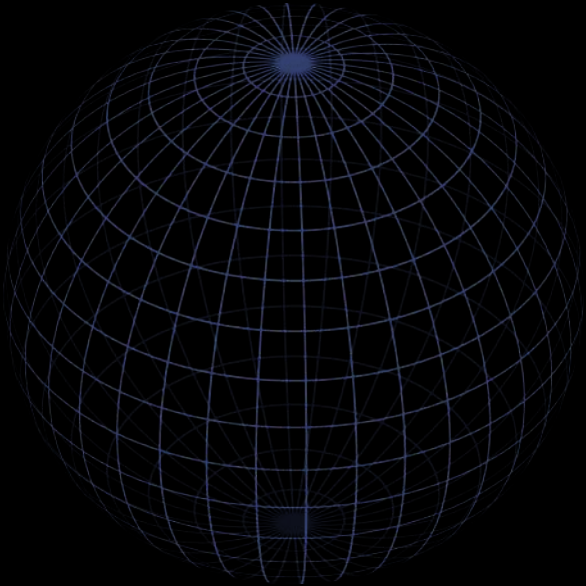


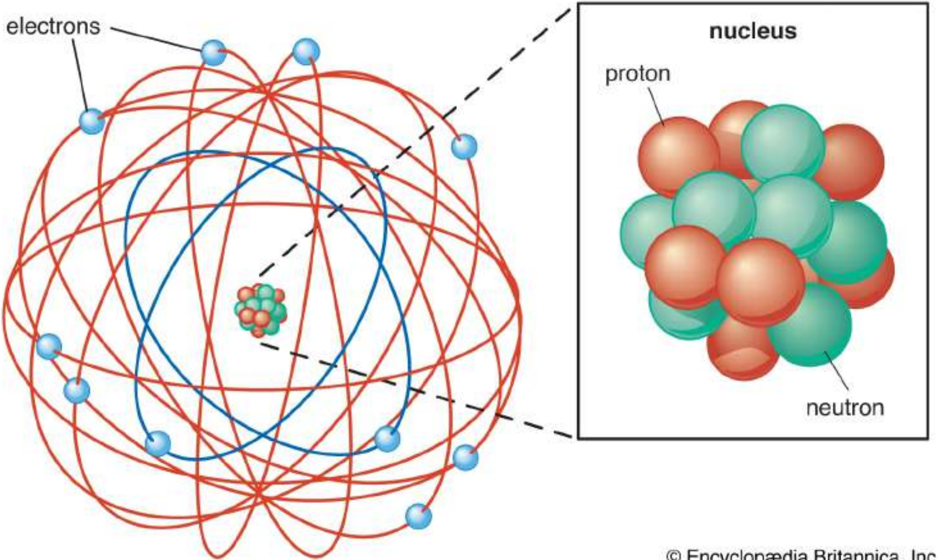
Image Credits: Wikipedia

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

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

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

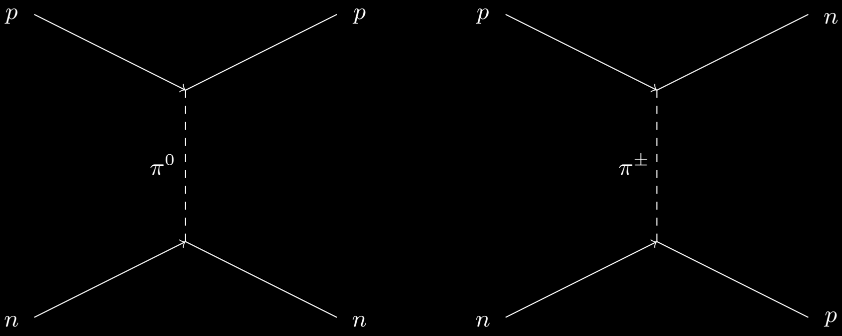
$$F = \frac{GmM}{r^2} \qquad F = k\frac{qQ}{r^2}$$


electrons
nucleus
proton
neutron

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.

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

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



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

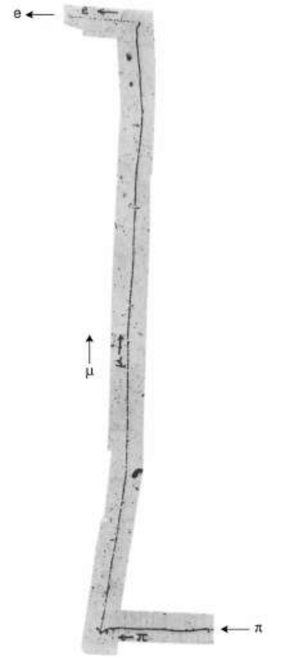
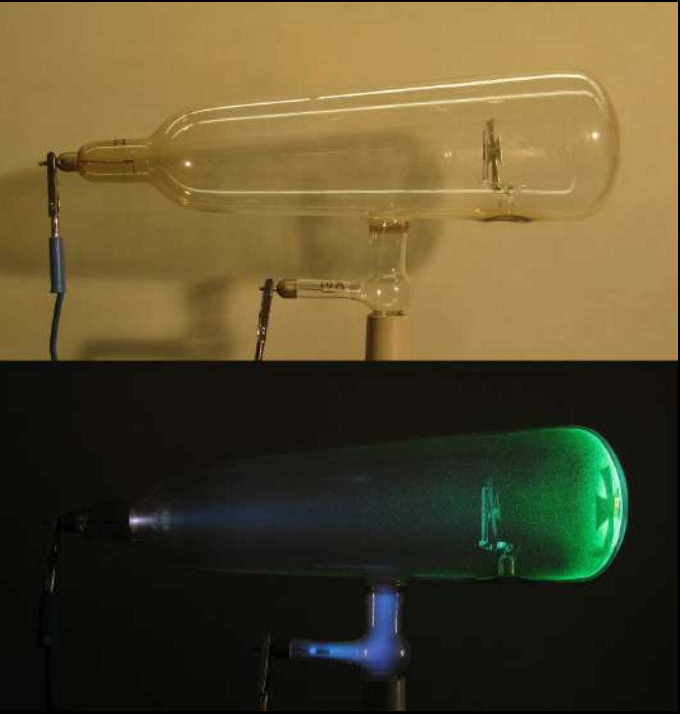


Image Credits: C. Powell

Image Credits: Mivar



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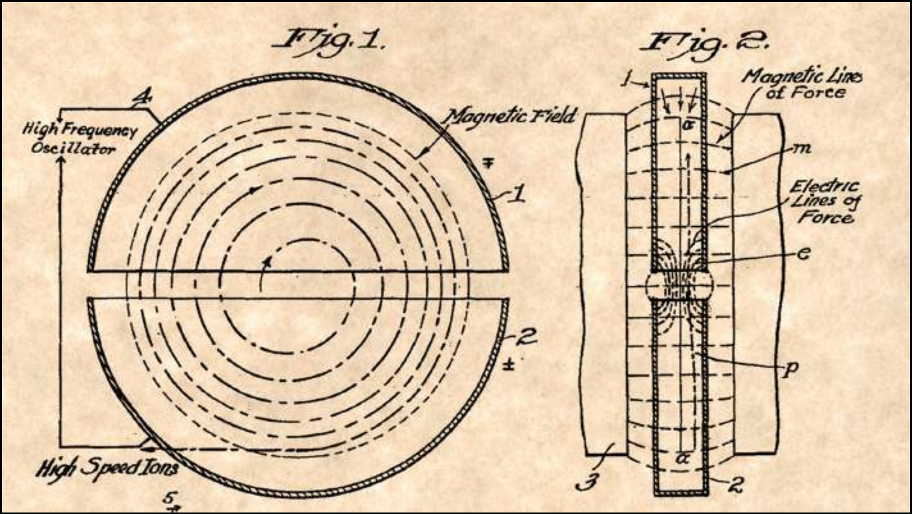


Image Credits: E. Lawrence

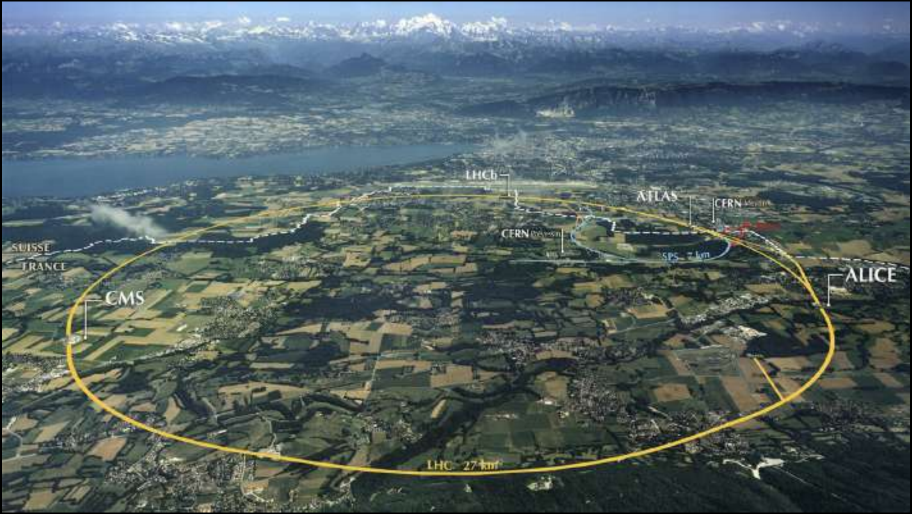
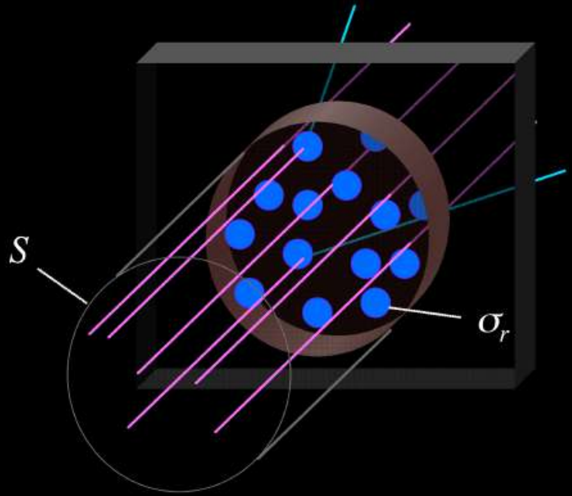


Image Credits: CERN

$$e^-, \nu, \mu^-$$
$$n, p,$$
$$\pi^+, \pi^0,$$
$$\Delta^+, \Delta^+, \Delta^0,$$
$$\Sigma^0, \Sigma^+, \Lambda^0,$$
$$K^+, K^0$$
$$\Xi^+, \Xi^0, \ldots$$


S
σ_r

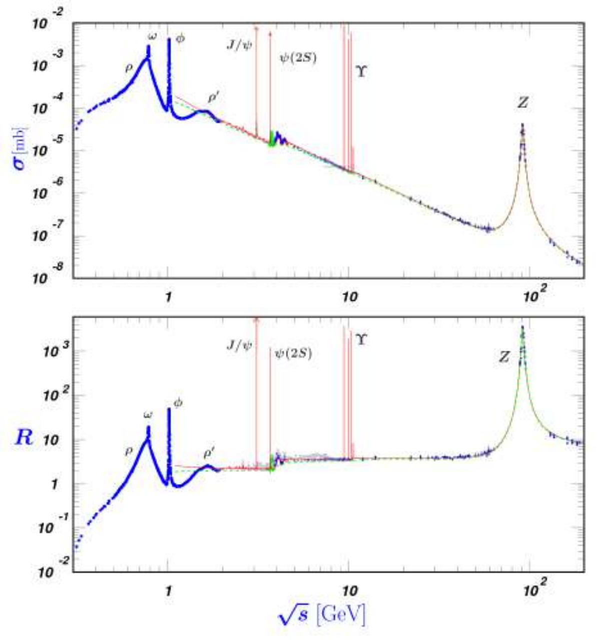


Image Credits: CERN

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

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

$$E = E_1 + E_2$$

$$p = p_1 + p_2$$

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

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

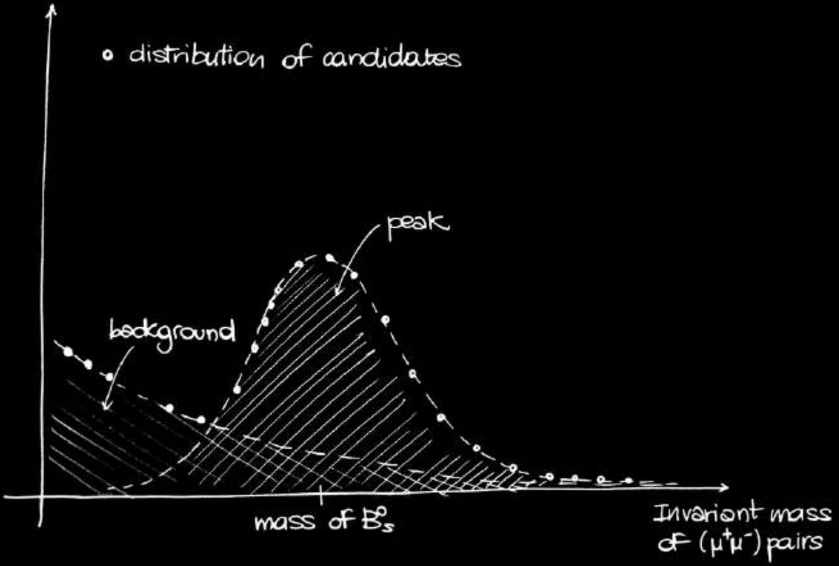
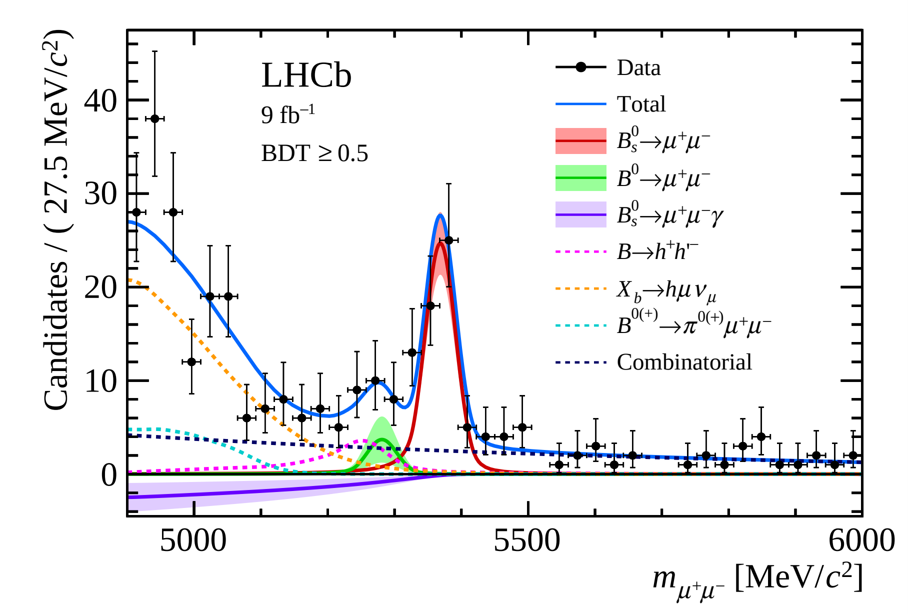


Image Credits: S. Oggero



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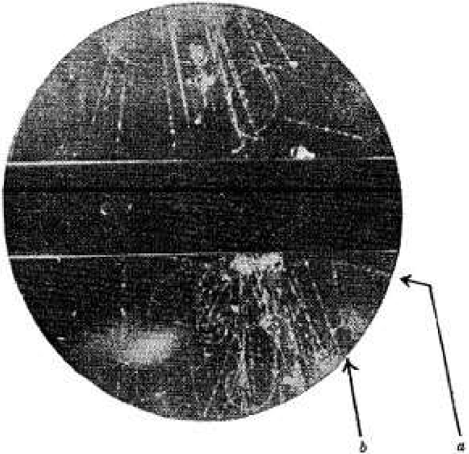


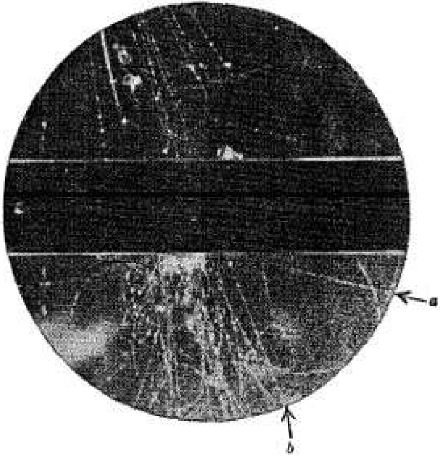
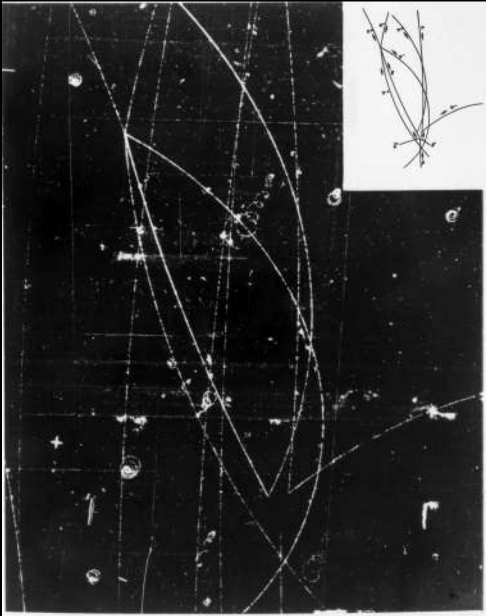
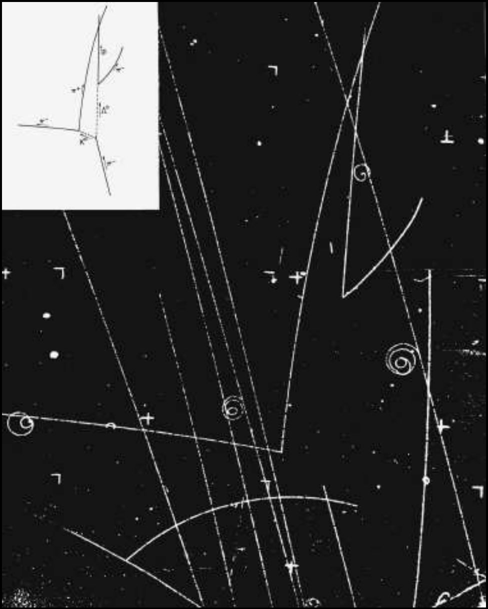


Image Credits: D. Rochester, C. C. Butler, Nature 160 (1947) 855-857



Production and decay of neutral lambda and anti—lambda hyperons

Image Credits: Lawrence Berkeley National Laboratory



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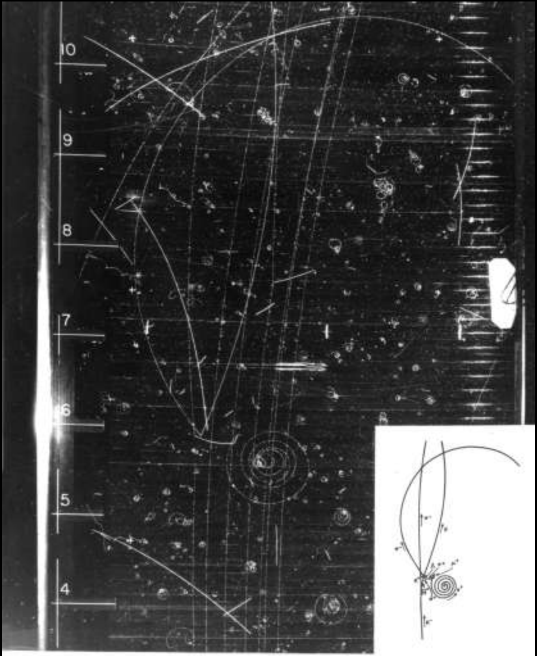


Production and decay of a xi zero

Image Credits: Lawrence Berkeley National Laboratory

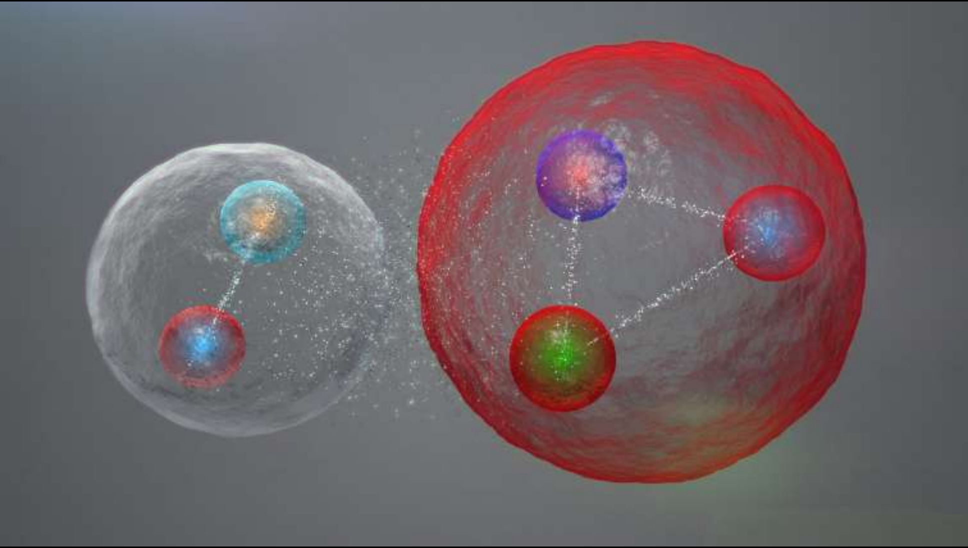
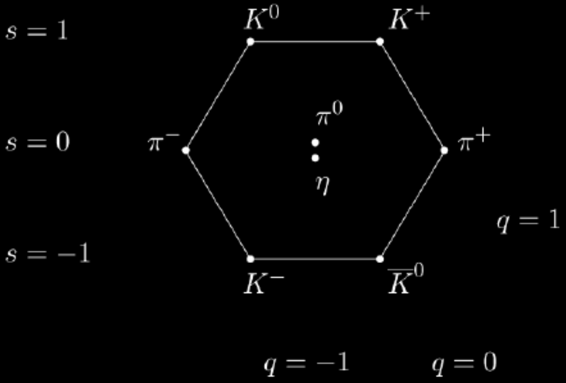


Image Credits: CERN

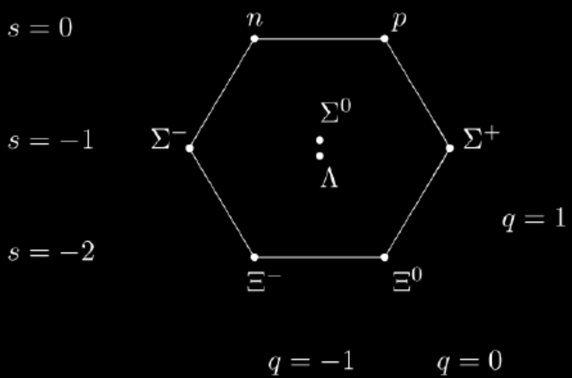
	Fermioni			Bosoni
	Spin 1/2 …			Spin 0, 1 …
	Leptoni	Adroni		
		Barioni		Mesoni
	e, μ, ν	p, n,		π, π^0
Strani		Λ, Σ, …		K, K^0

Conservazione	Avviene	NON avviene
Massa / energia	$n \to pe^- \bar{\nu}_e$	$p \to ne^+ \nu_e$ *
Carica elettrica	$n \to pe^- \bar{\nu}_e$	$e^- \to \gamma \nu_e$
Numero e “flavour” leptonico	$n \to pe^- \bar{\nu}_e$ $\mu^- \to e^- \bar{\nu}_e \nu_\mu$	$n \to pe^- \gamma$ $\mu^- \to e^- \gamma$
Numero barionico	$\gamma \to p\bar{p}$	$p \to \pi^+ \gamma$
Stranezza	$pp \to \Lambda^0 \bar{n} K^0 \gamma$ $\Lambda^0 \to p\pi^-$ *	$pp \to \Lambda \bar{n} \gamma$

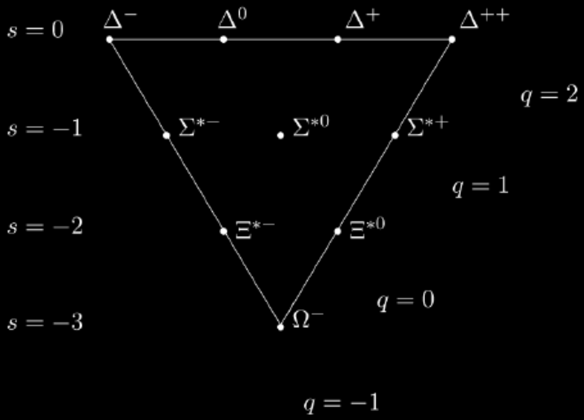
*Alcune di queste reazioni possono avvenire in determinate condizioni o tramite diverse interazioni...



s = 1
s = 0
s = −1
K0
K+
π−
π0
η
π+
K−
K̄0
q = 1
q = −1
q = 0



s = 0
s = −1
s = −2
n
p
Σ⁰
Λ
Σ⁻
Σ⁺
Ξ⁻
Ξ⁰
q = 1
q = −1
q = 0



$s = 0$
$s = -1$
$s = -2$
$s = -3$
Δ^-
Δ^0
Δ^+
Δ^{++}
Σ^{*-}
Σ^{*0}
Σ^{*+}
Ξ^{*-}
Ξ^{*0}
Ω^-
$q = 2$
$q = 1$
$q = 0$
$q = -1$

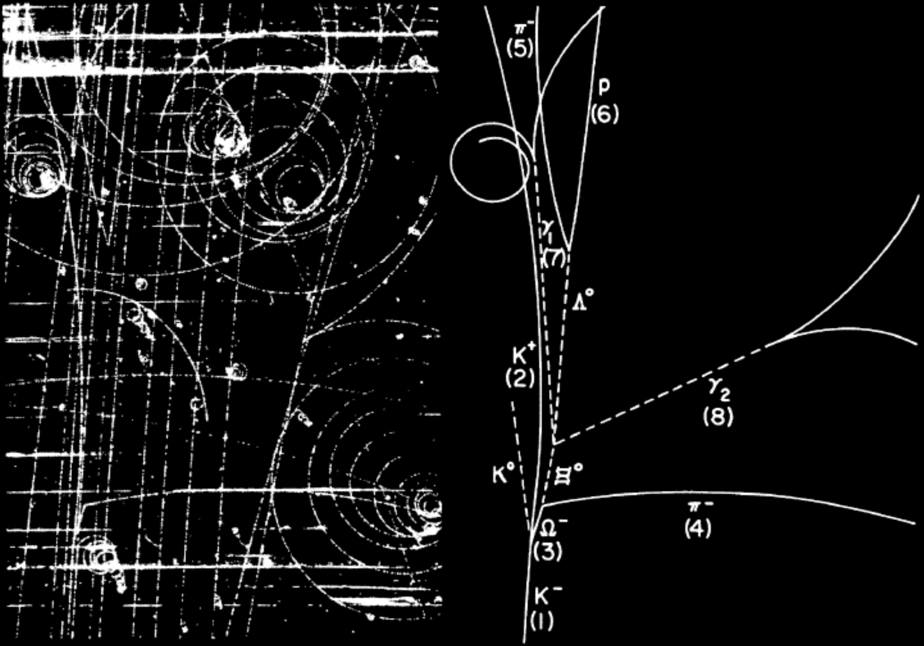


Image Credits: V. E. Barnes et al. Phys. Rev. Lett. 12, 204

$ep \rightarrow \ldots$ Deep inelastic scattering

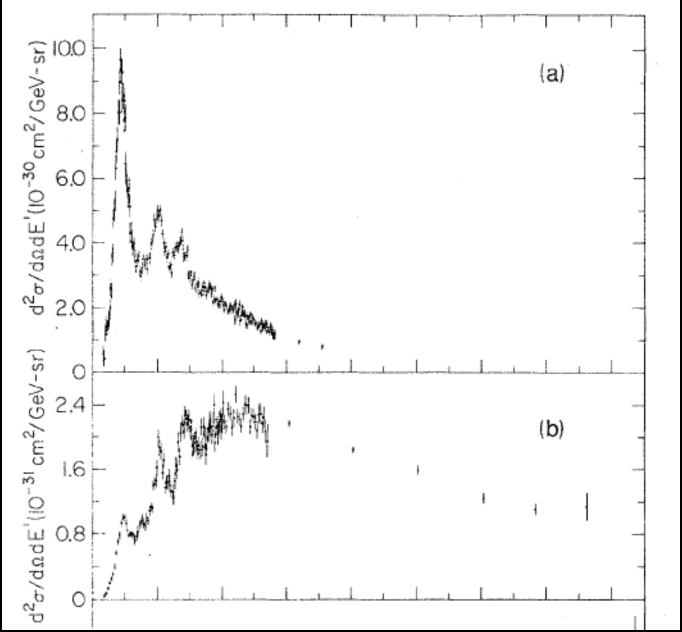
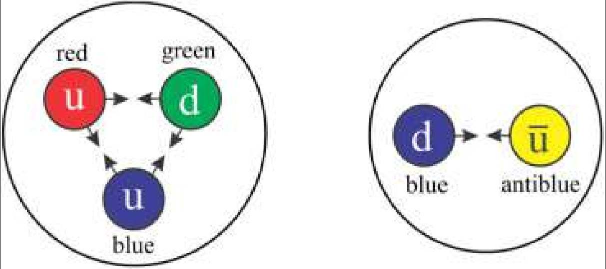


Image Credits: Bloom et al. Phys. Rev. Lett. 23, 930 (1969)

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
n	0	1/2	$\bar{u}\bar{d}\bar{d}$
π^+	+1	0	$u\bar{d}$
π^-	+1	0	$u\bar{d}$
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^-)

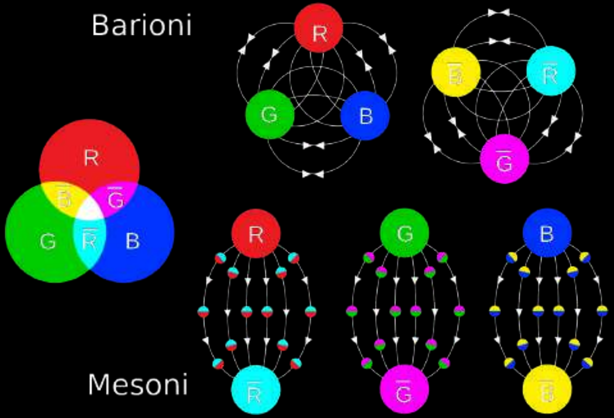
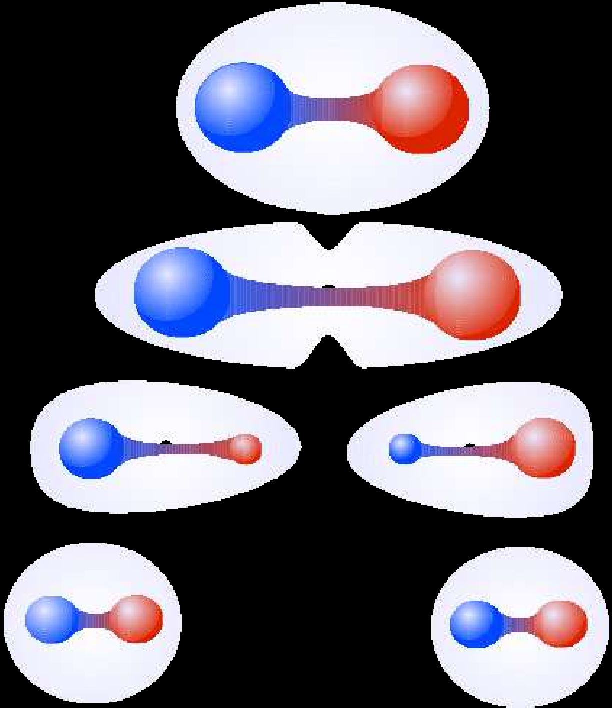


Image Credits: Wikipedia



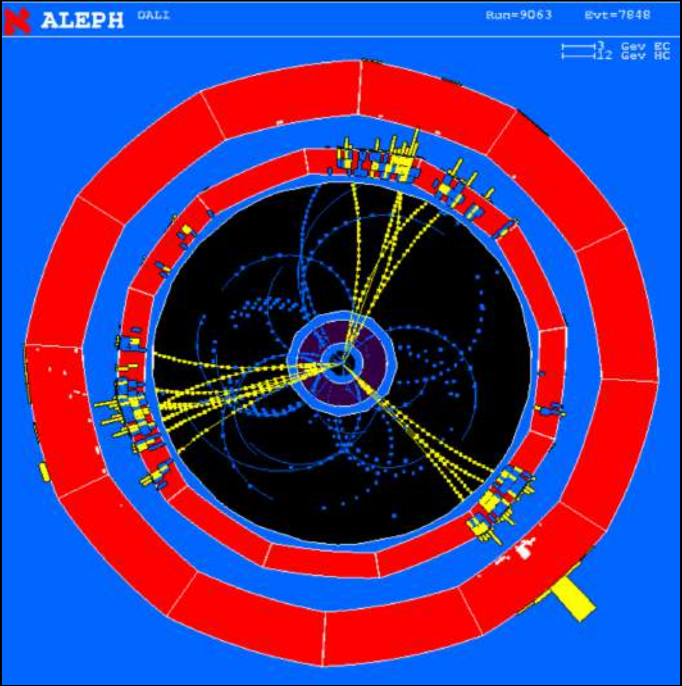


Image Credits: CERN

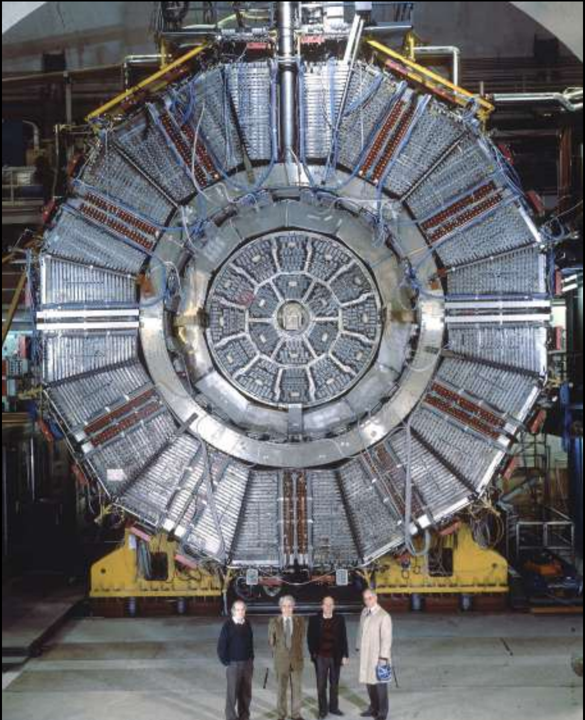
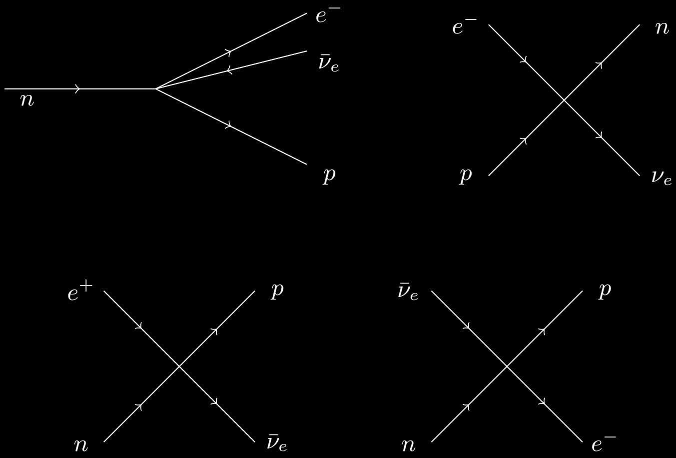


Image Credits: CERN



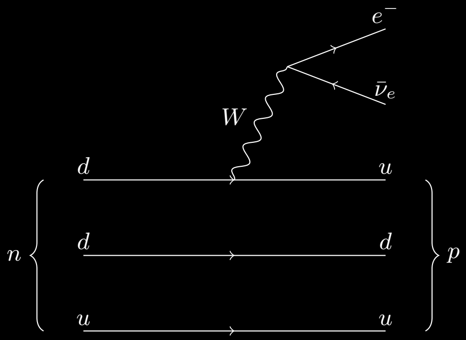
e^-
$\bar{\nu}_e$
n
p
e^-
n
p
ν_e
e^+
p
n
$\bar{\nu}_e$
$\bar{\nu}_e$
p
n
e^-

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

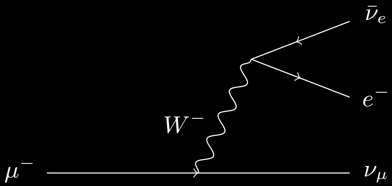
$$F = \mathbf{k}\frac{qQ}{r^2}$$

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

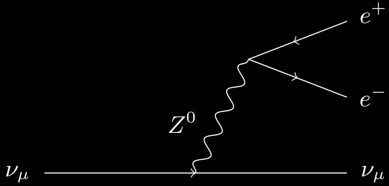
$$F \propto \mathbf{G_F} \qquad ? \qquad F \propto \mathbf{k}e^{-\omega r}$$



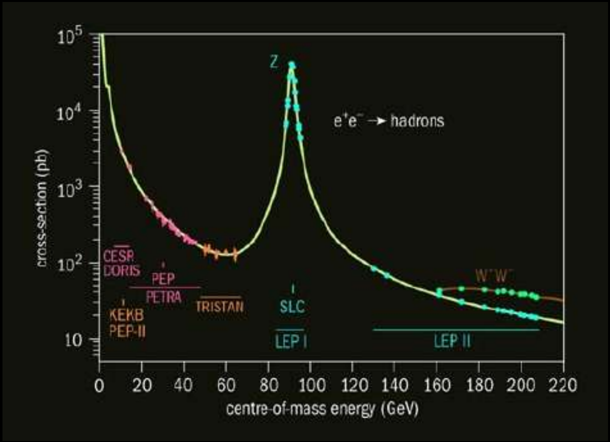
e^-
$\bar{\nu}_e$
W
d
u
n
d
d
p
u
u



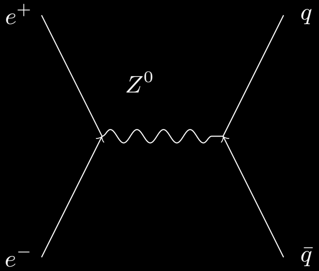
$\bar{\nu}_e$
e^-
W^-
μ^-
ν_μ



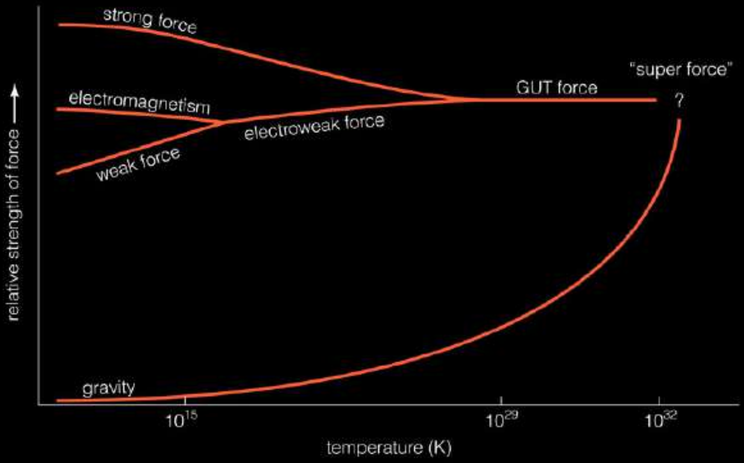
e^+
e^-
Z^0
ν_μ
ν_μ



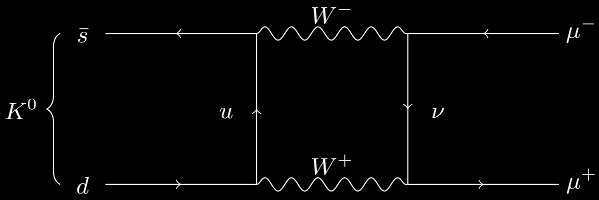
e⁺e⁻ → hadrons
Z
W⁺W⁻
CESR
DORIS
PEP
PETRA
KEKB
PEP-II
TRISTAN
SLC
LEP I
LEP II
cross-section (pb)
centre-of-mass energy (GeV)



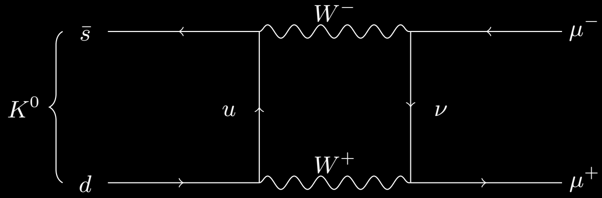
e^+
q
Z^0
e^-
$\bar{q}$


strong force
electromagnetism
weak force
electroweak force
GUT force
"super force"
?
gravity
relative strength of force
10^{15}
10^{29}
10^{32}
temperature (K)

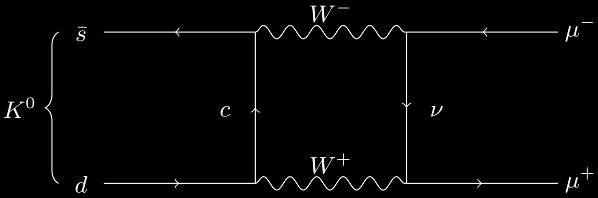
$$K^0 \to \mu^+ \mu^-$$

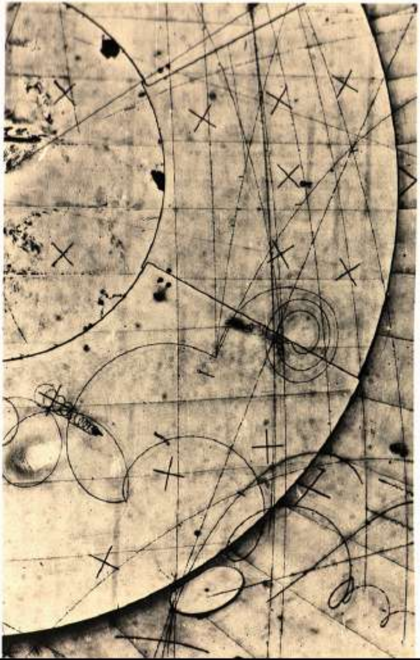


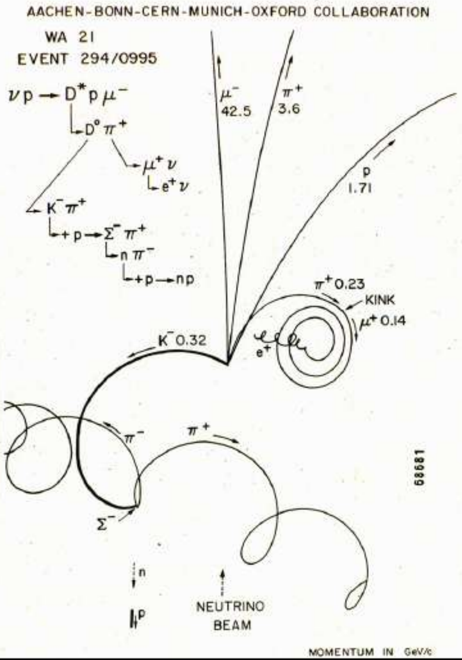
$$K^0 \to \mu^+\mu^-$$

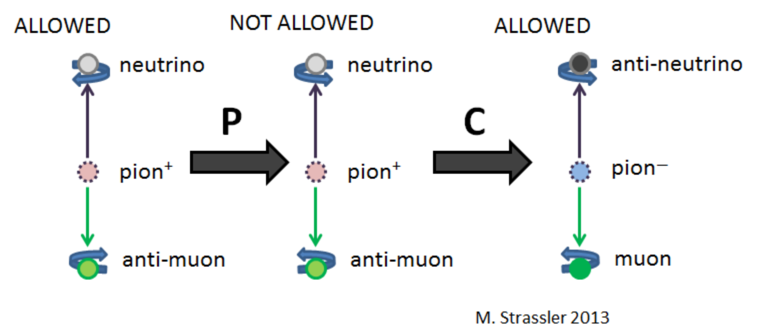


—






AACHEN-BONN-CERN-MUNICH-OXFORD COLLABORATION
WA 21
EVENT 294/0995
νp → D*pμ⁻
D°π⁺
μ⁺ν
e⁺ν
K⁻π⁺
+ p → Σ⁻π⁺
nπ⁻
+ p → np
μ⁻
42.5
π⁺
3.6
p
1.71
π⁺ 0.23
KINK
μ⁺ 0.14
K⁻ 0.32
e⁺
π⁻
π⁺
Σ⁻
n
p
NEUTRINO
BEAM
68681
MOMENTUM IN GeV/c


ALLOWED
NOT ALLOWED
ALLOWED
neutrino
neutrino
anti-neutrino
P
C
pion+
pion+
pion–
anti-muon
anti-muon
muon
M. Strassler 2013

$$^{60}_{27}\mathrm{Co} \rightarrow^{60}_{28} \mathrm{Ni} \rightarrow \mathrm{e}^{-}\nu_{\mathrm{e}}$$

Image Credits: Columbia University

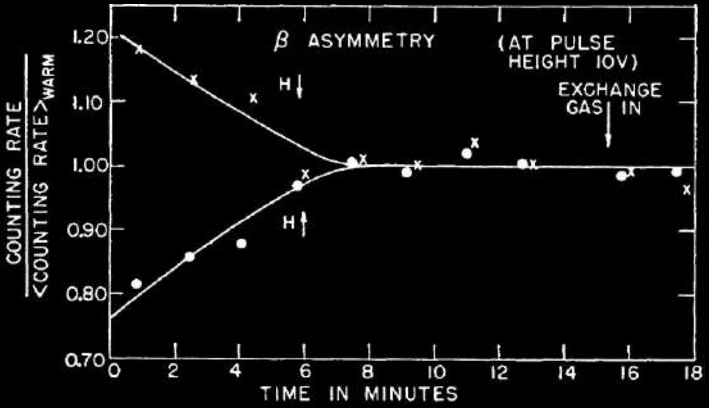
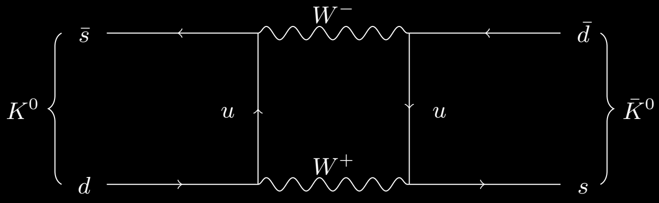


Image Credits: C. S. Wu, et al. - Phys. Rev. 105, 1413


W^-
$\bar{s}$
$\bar{d}$
K^0
u
u
$\bar{K}^0$
W^+
d
s

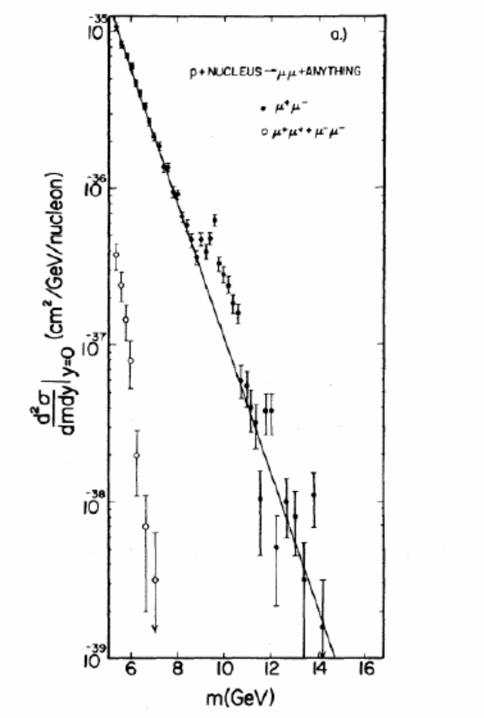


Image Credits: Fermilab

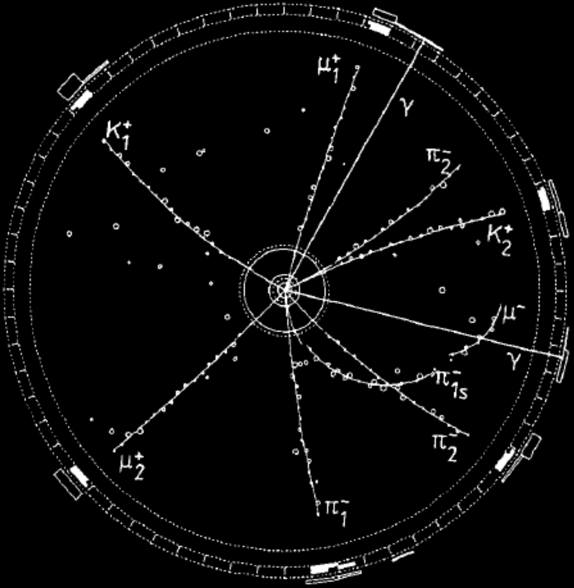


Image Credits: SLAC

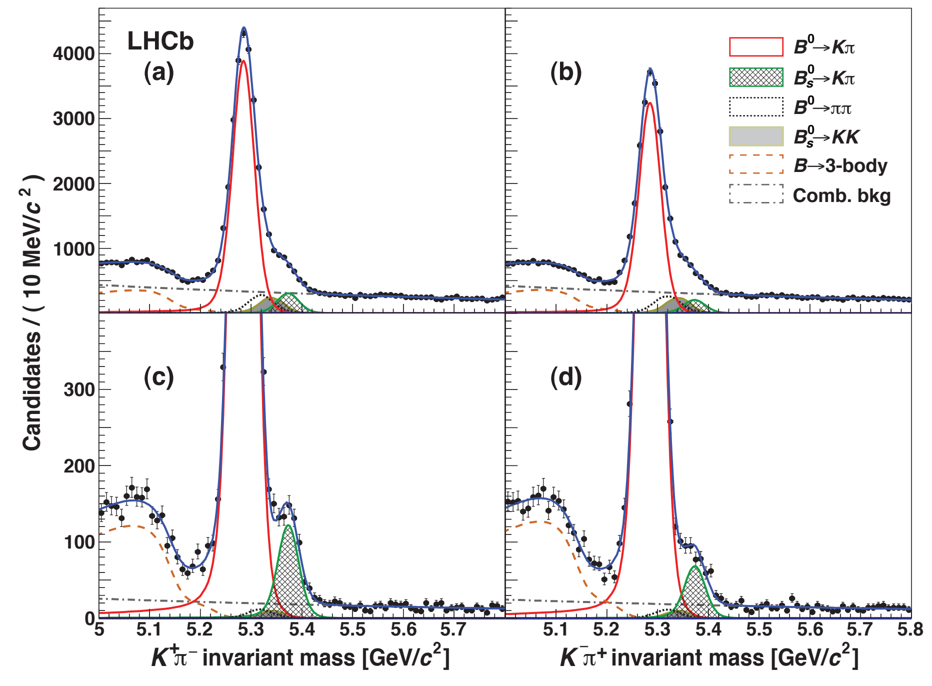


Image Credits: CERN

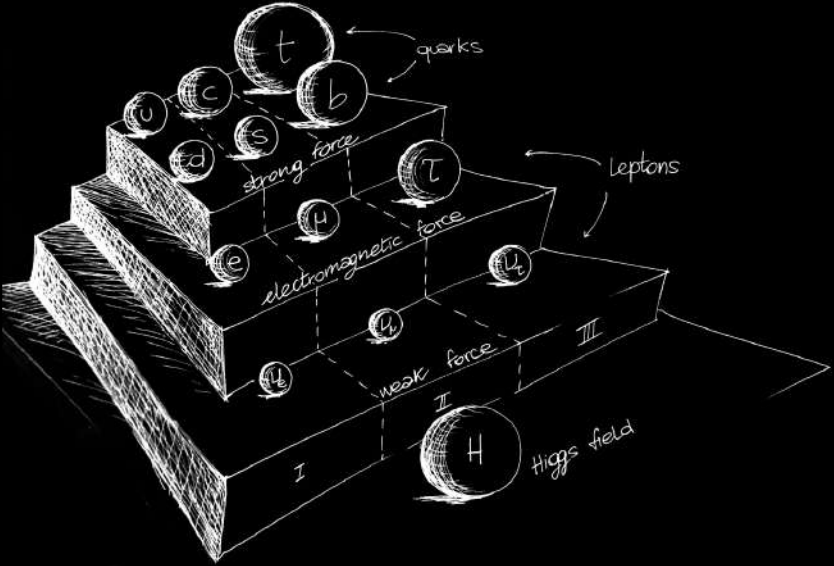
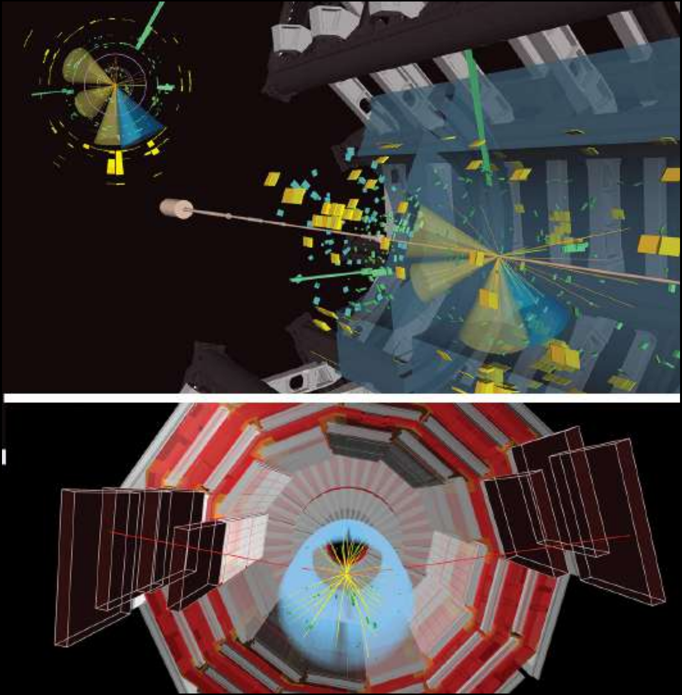


Image Credits: S. Oggero



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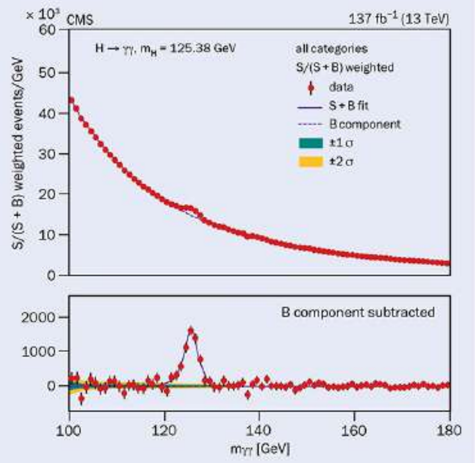


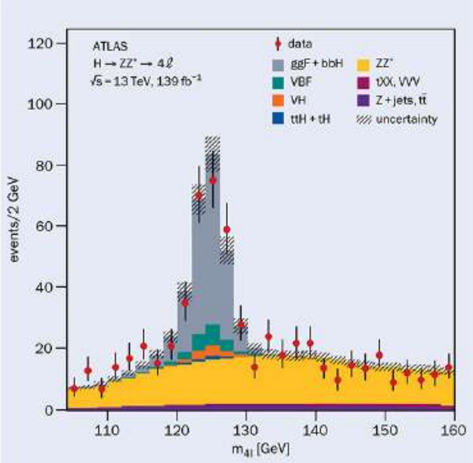
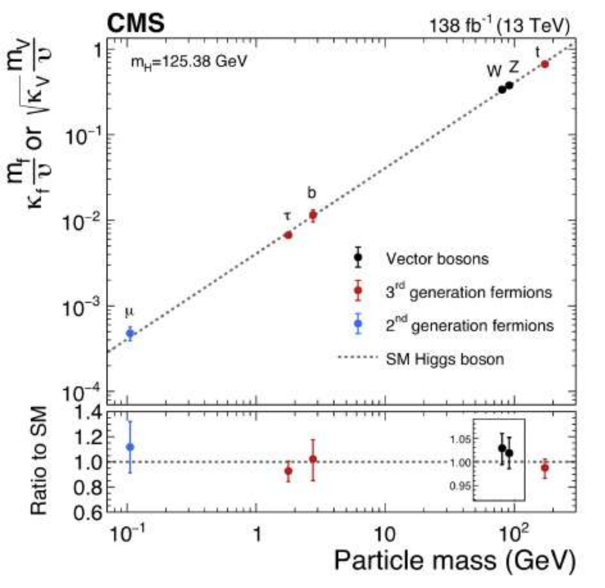


Image Credits: CERN



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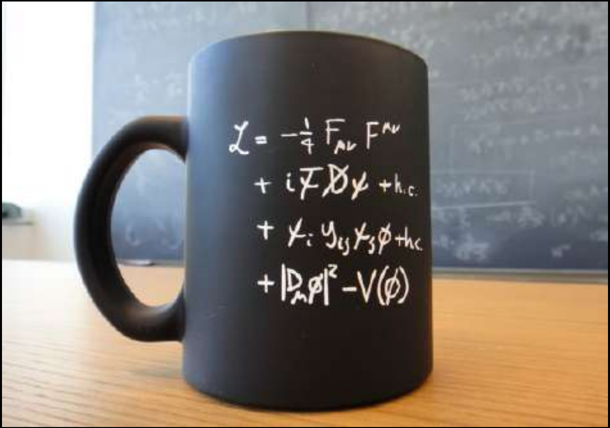


Image Credits: CERN

1

$$-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4}g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu + \frac{1}{2}ig_s^2(\bar{q}^\sigma_i \gamma^\mu q^\sigma_j)g^a_\mu + \bar{G}^a\partial^2 G^a + g_s f^{abc}\partial_\mu \bar{G}^a G^b g^c_\mu$$

2

$$-\partial_\nu W^+_\mu \partial_\nu W^-_\mu - M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c_w^2}M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H - \frac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\mu \phi^- - M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\mu \phi^0 - \frac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h\left[\frac{2M^2}{g^2} + \frac{2M}{g}H + \frac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)\right] + \frac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z^0_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - Z^0_\nu(W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + Z^0_\mu(W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - igs_w[\partial_\nu A_\mu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - A_\nu(W^+_\mu \partial_\nu W^-_\mu - W^-_\mu \partial_\nu W^+_\mu) + A_\mu(W^+_\nu \partial_\nu W^-_\mu - W^-_\nu \partial_\nu W^+_\mu)] - \frac{1}{2}g^2 W^+_\mu W^-_\mu W^+_\nu W^-_\nu + \frac{1}{2}g^2 W^+_\mu W^-_\nu W^+_\mu W^-_\nu + g^2 c_w^2(Z^0_\mu W^+_\mu Z^0_\nu W^-_\nu - Z^0_\mu Z^0_\mu W^+_\nu W^-_\nu) + g^2 s_w^2(A_\mu W^+_\mu A_\nu W^-_\nu - A_\mu A_\mu W^+_\nu W^-_\nu) + g^2 s_w c_w[A_\mu Z^0_\nu(W^+_\mu W^-_\nu - W^+_\nu W^-_\mu) - 2A_\mu Z^0_\mu W^+_\nu W^-_\nu] - g\alpha[H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] - \frac{1}{8}g^2\alpha_h[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2H^2] - gMW^+_\mu W^-_\mu H - \frac{1}{2}g\frac{M}{c_w^2}Z^0_\mu Z^0_\mu H - \frac{1}{2}ig[W^+_\mu(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) - W^-_\mu(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)] + \frac{1}{2}g[W^+_\mu(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W^-_\mu(H\partial_\mu\phi^+ - \phi^+\partial_\mu H)] + \frac{1}{2}g\frac{1}{c_w}(Z^0_\mu(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) - ig\frac{s_w^2}{c_w}MZ^0_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) + igs_w MA_\mu(W^+_\mu\phi^- - W^-_\mu\phi^+) - ig\frac{1-2c_w^2}{2c_w}Z^0_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) + igs_w A_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \frac{1}{4}g^2 W^+_\mu W^-_\mu[H^2 + (\phi^0)^2 + 2\phi^+\phi^-] - \frac{1}{4}g^2\frac{1}{c_w^2}Z^0_\mu Z^0_\mu[H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2\phi^+\phi^-] - \frac{1}{2}g^2\frac{s_w^2}{c_w}Z^0_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) - \frac{1}{2}ig^2\frac{s_w^2}{c_w}Z^0_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) + \frac{1}{2}g^2 s_w A_\mu\phi^0(W^+_\mu\phi^- + W^-_\mu\phi^+) + \frac{1}{2}ig^2 s_w A_\mu H(W^+_\mu\phi^- - W^-_\mu\phi^+) - g^2\frac{s_w}{c_w}(2c_w^2 - 1)Z^0_\mu A_\mu\phi^+\phi^- - g^2 s_w^2 A_\mu A_\mu\phi^+\phi^-$$

3

$$-\bar{e}^\lambda(\gamma\partial + m_e^\lambda)e^\lambda - \bar{\nu}^\lambda\gamma\partial\nu^\lambda - \bar{u}^\lambda_j(\gamma\partial + m_u^\lambda)u^\lambda_j - \bar{d}^\lambda_j(\gamma\partial + m_d^\lambda)d^\lambda_j + igs_w A_\mu\left[-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}^\lambda_j\gamma^\mu u^\lambda_j) - \frac{1}{3}(\bar{d}^\lambda_j\gamma^\mu d^\lambda_j)\right] + \frac{ig}{4c_w}Z^0_\mu\left[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(\tfrac{4}{3}s_w^2 - 1 - \gamma^5)u^\lambda_j) + (\bar{d}^\lambda_j\gamma^\mu(1 - \tfrac{8}{3}s_w^2 - \gamma^5)d^\lambda_j)\right] + \frac{ig}{2\sqrt{2}}W^+_\mu\left[(\bar{\nu}^\lambda\gamma^\mu(1+\gamma^5)e^\lambda) + (\bar{u}^\lambda_j\gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d^\kappa_j)\right] + \frac{ig}{2\sqrt{2}}W^-_\mu\left[(\bar{e}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}^\kappa_j C^\dagger_{\lambda\kappa}\gamma^\mu(1+\gamma^5)u^\lambda_j)\right]$$

4

$$+\frac{ig}{2\sqrt{2}}\frac{m_e^\lambda}{M}\left[-\phi^+(\bar{\nu}^\lambda(1-\gamma^5)e^\lambda) + \phi^-(\bar{e}^\lambda(1+\gamma^5)\nu^\lambda)\right] - \frac{g}{2}\frac{m_e^\lambda}{M}\left[H(\bar{e}^\lambda e^\lambda) + i\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda)\right] + \frac{ig}{2M\sqrt{2}}\phi^+\left[-m_d^\kappa(\bar{u}^\lambda_j C_{\lambda\kappa}(1-\gamma^5)d^\kappa_j) + m_u^\lambda(\bar{u}^\lambda_j C_{\lambda\kappa}(1+\gamma^5)d^\kappa_j)\right] + \frac{ig}{2M\sqrt{2}}\phi^-\left[m_d^\lambda(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1+\gamma^5)u^\kappa_j) - m_u^\kappa(\bar{d}^\lambda_j C^\dagger_{\lambda\kappa}(1-\gamma^5)u^\kappa_j)\right] - \frac{g}{2}\frac{m_u^\lambda}{M}H(\bar{u}^\lambda_j u^\lambda_j) - \frac{g}{2}\frac{m_d^\lambda}{M}H(\bar{d}^\lambda_j d^\lambda_j) + \frac{ig}{2}\frac{m_u^\lambda}{M}\phi^0(\bar{u}^\lambda_j\gamma^5 u^\lambda_j) - \frac{ig}{2}\frac{m_d^\lambda}{M}\phi^0(\bar{d}^\lambda_j\gamma^5 d^\lambda_j)$$

5

$$+\bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \frac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2 Y + igc_w W^+_\mu(\partial_\mu\bar{X}^0 X^- - \partial_\mu\bar{X}^+ X^0) + igs_w W^+_\mu(\partial_\mu\bar{Y}X^- - \partial_\mu\bar{X}^+ Y) + igc_w W^-_\mu(\partial_\mu\bar{X}^- X^0 - \partial_\mu\bar{X}^0 X^+) + igs_w W^-_\mu(\partial_\mu\bar{X}^- Y - \partial_\mu\bar{Y}X^+) + igc_w Z^0_\mu(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) - \frac{1}{2}gM\left[\bar{X}^+X^+H + \bar{X}^-X^-H + \frac{1}{c_w^2}\bar{X}^0X^0H\right] + \frac{1-2c_w^2}{2c_w}igM\left[\bar{X}^+X^0\phi^+ - \bar{X}^-X^0\phi^-\right] + \frac{1}{2c_w}igM\left[\bar{X}^0X^-\phi^+ - \bar{X}^0X^+\phi^-\right] + igMs_w\left[\bar{X}^0X^-\phi^+ - \bar{X}^0X^+\phi^-\right] + \frac{1}{2}igM\left[\bar{X}^+X^+\phi^0 - \bar{X}^-X^-\phi^0\right]$$

Image Credits: Particle Data Group

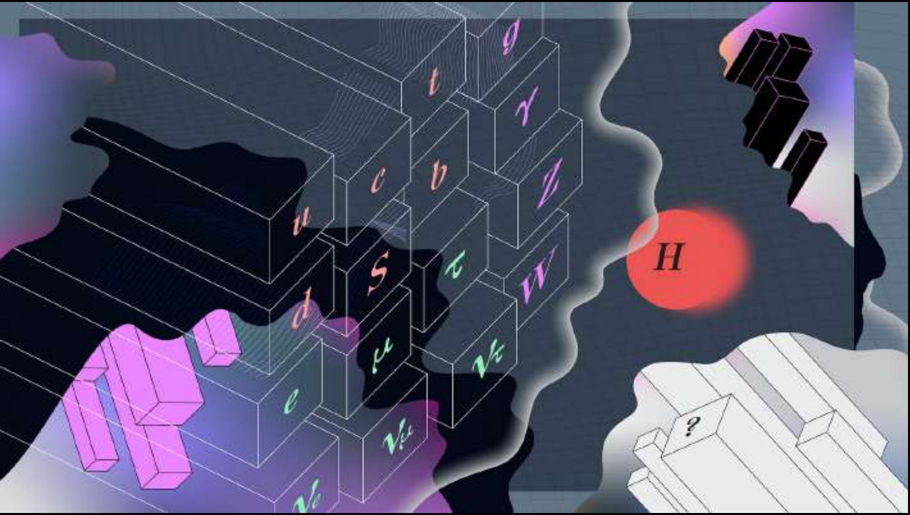
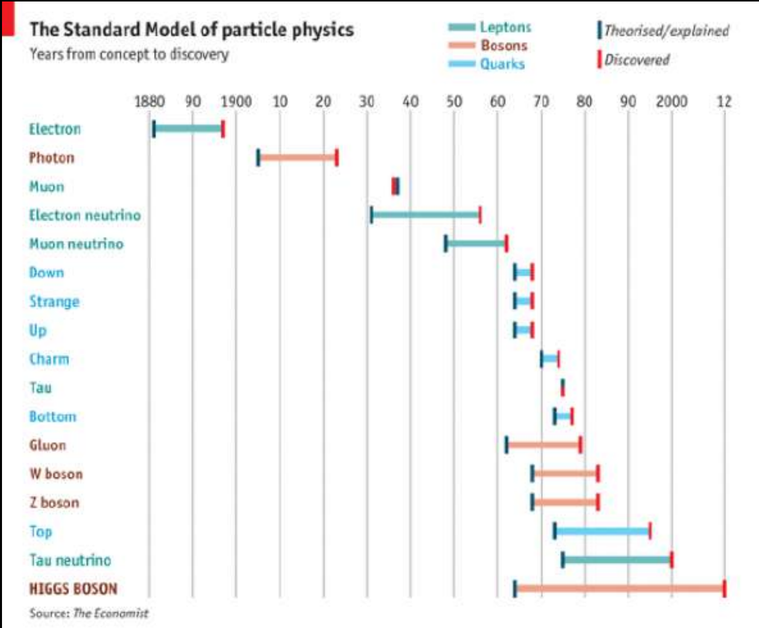
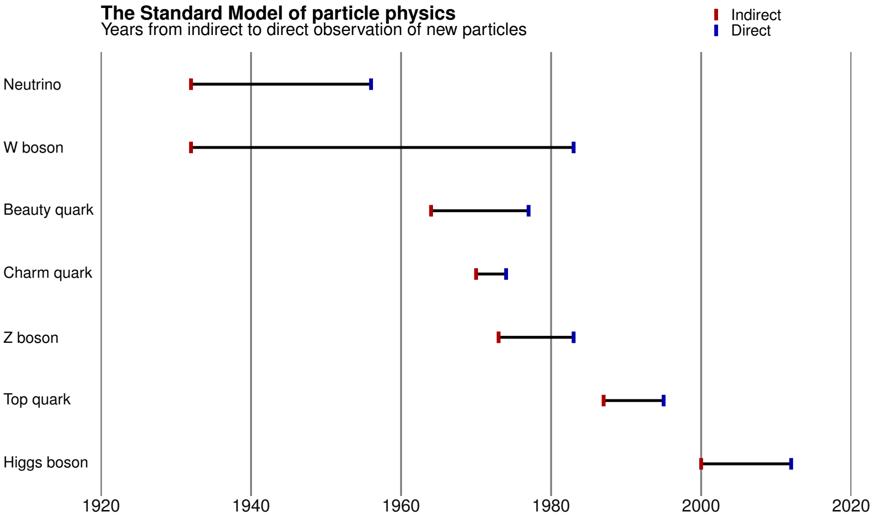


Image Credits: Symmetry Magazine



The Standard Model of particle physics
Years from concept to discovery
Leptons
Bosons
Quarks
Theorised/explained
Discovered
1880
90
1900
10
20
30
40
50
60
70
80
90
2000
12
Electron
Photon
Muon
Electron neutrino
Muon neutrino
Down
Strange
Up
Charm
Tau
Bottom
Gluon
W boson
Z boson
Top
Tau neutrino
HIGGS BOSON
Source: The Economist


The Standard Model of particle physics
Years from indirect to direct observation of new particles
Indirect
Direct
Neutrino
W boson
Beauty quark
Charm quark
Z boson
Top quark
Higgs boson
1920
1940
1960
1980
2000
2020

The end?

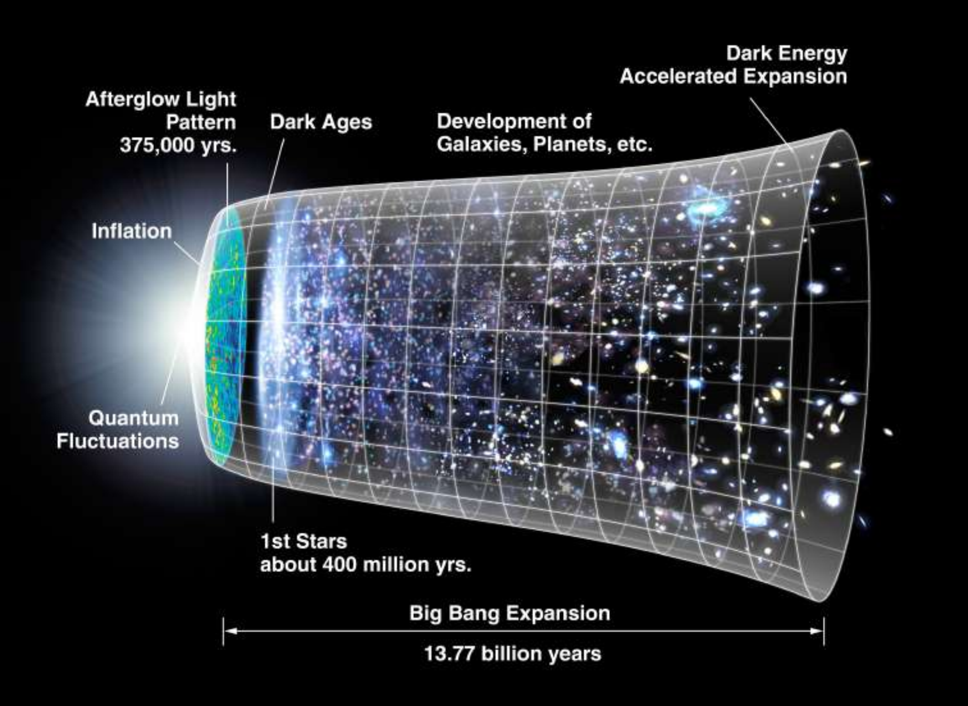
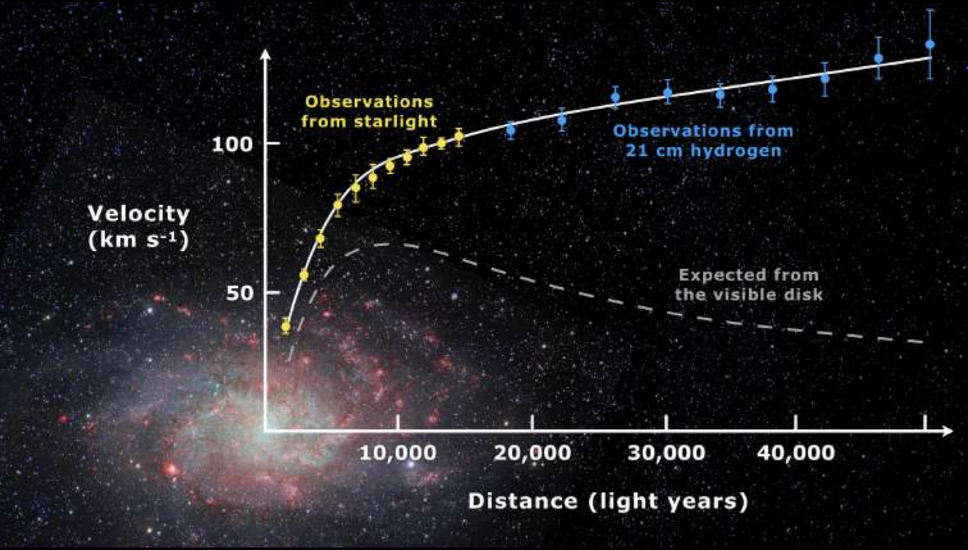


Image Credits: Wikipedia



Observations
from starlight
Observations from
21 cm hydrogen
100
Velocity
(km s-1)
50
Expected from
the visible disk
10,000
20,000
30,000
40,000
Distance (light years)

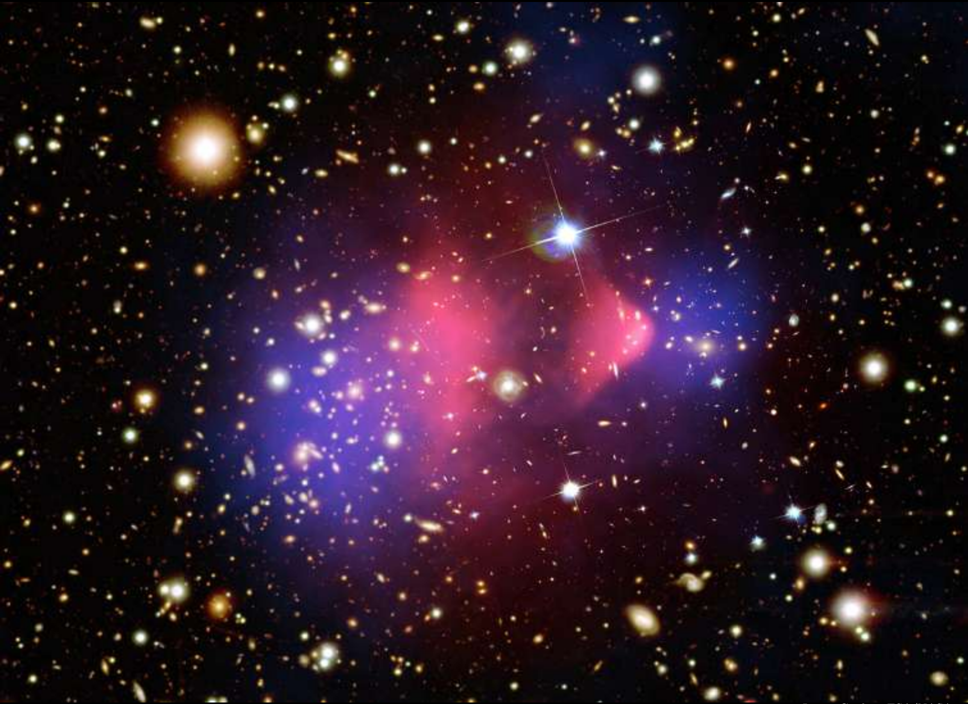


Image Credits: ESA/NASA

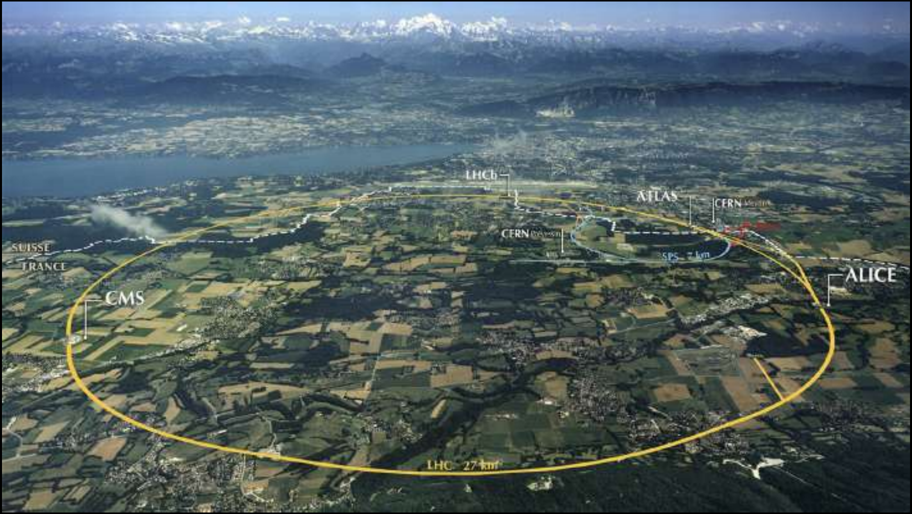
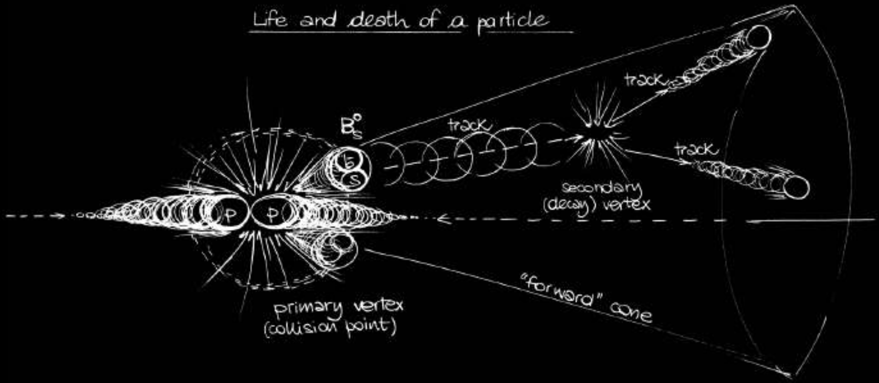
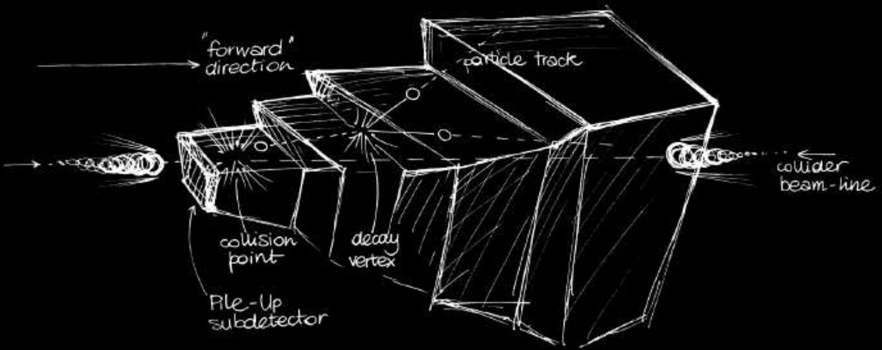


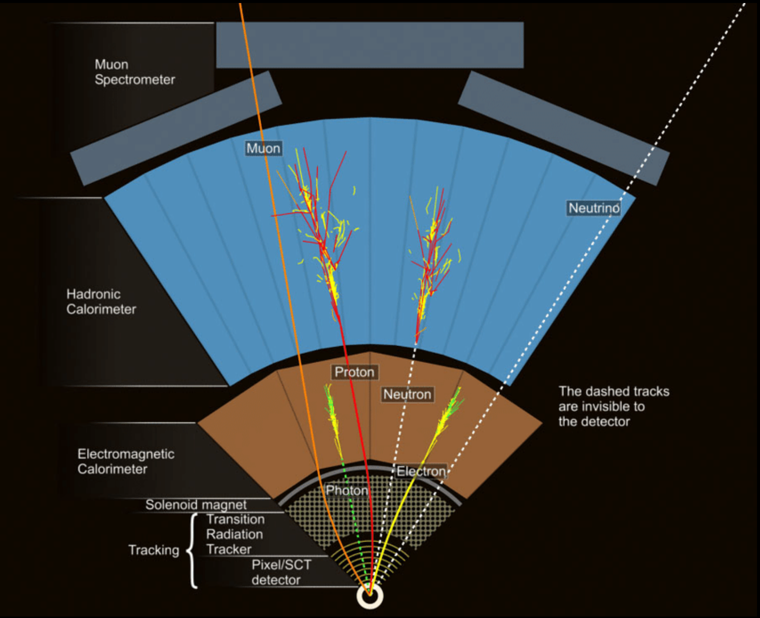
Image Credits: CERN

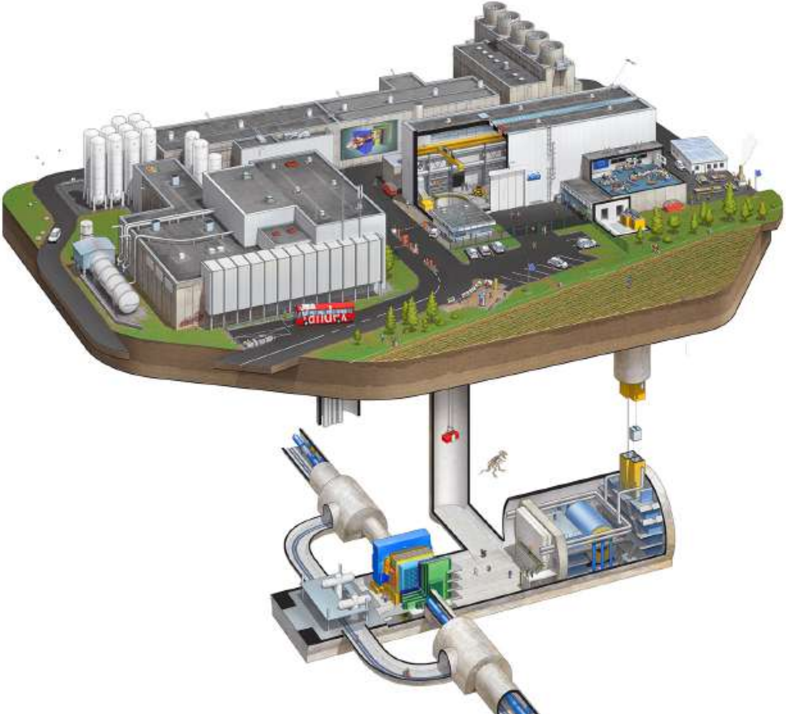

CMS
Control Center
LHCb
ALICE
ATLAS
Geneva

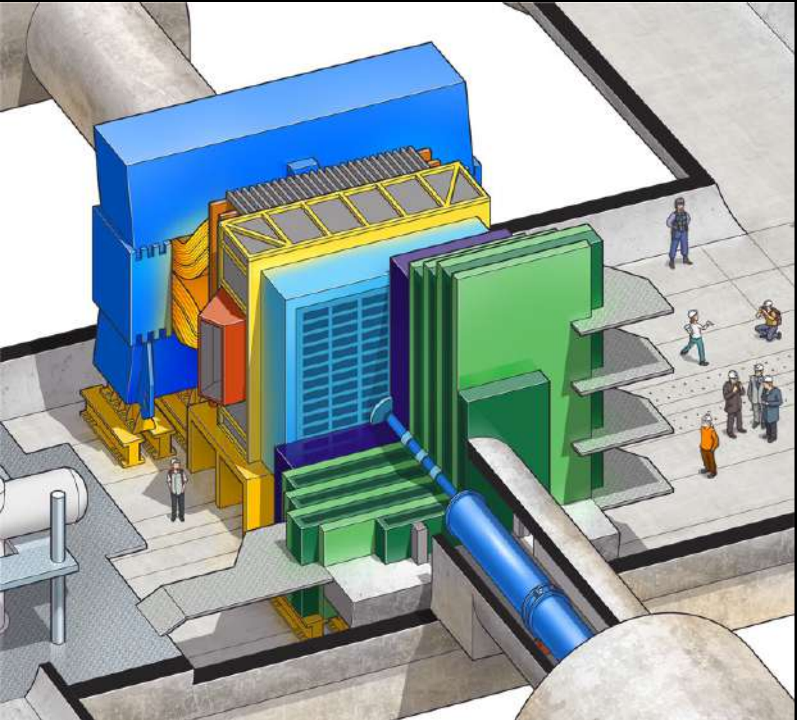

Life and death of a particle
B_s^0
b
s
p
p
track
track
track
secondary
(decay) vertex
primary vertex
(collision point)
"forward" cone

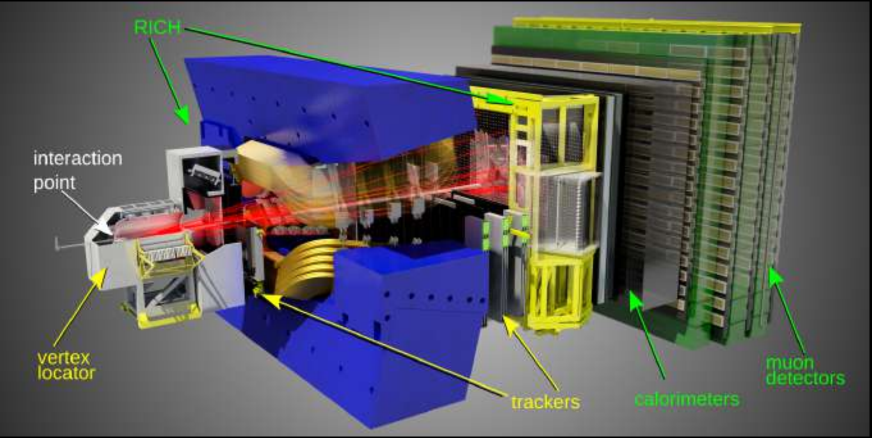
The LHCb "detecting box"




Muon Spectrometer
Muon
Neutrino
Hadronic Calorimeter
Proton
Neutron
The dashed tracks are invisible to the detector
Electromagnetic Calorimeter
Electron
Photon
Solenoid magnet
Tracking
Transition Radiation Tracker
Pixel/SCT detector

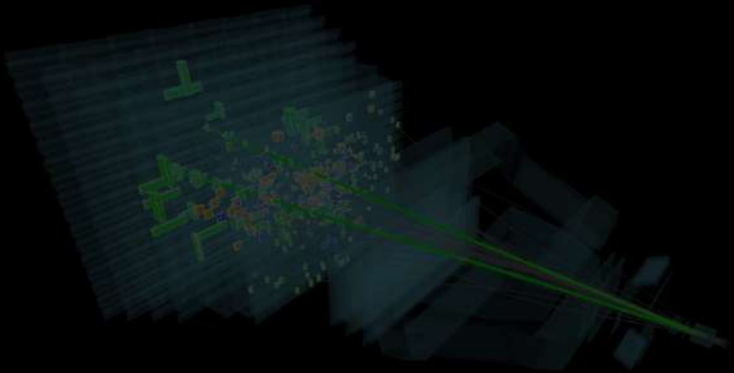





RICH
interaction point
vertex locator
trackers
calorimeters
muon detectors

LHCb è

- Antimateria (violazione CP)
- Nuove interazioni (con misure di precisione)
- Nuovi stati (pentaquark, tetraquark...)
- Dark matter con nuove particelle
- ....



The end?

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.*

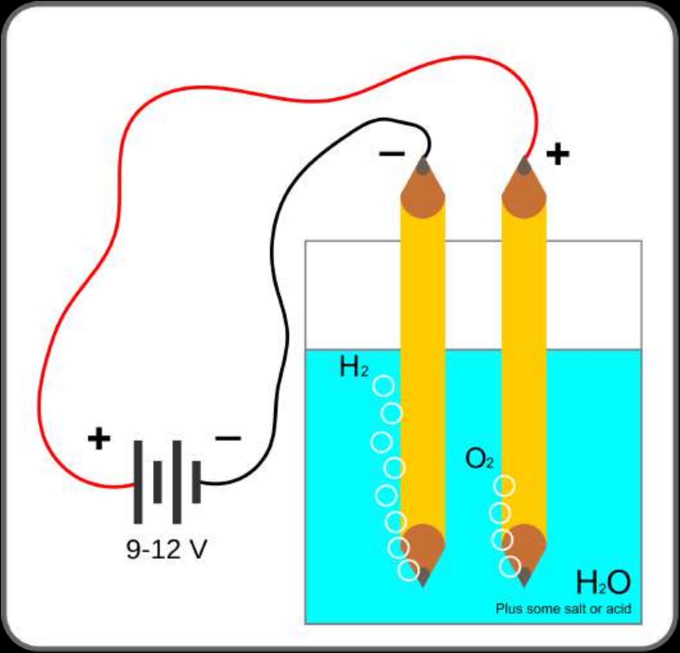


Image Credits: Wikipedia

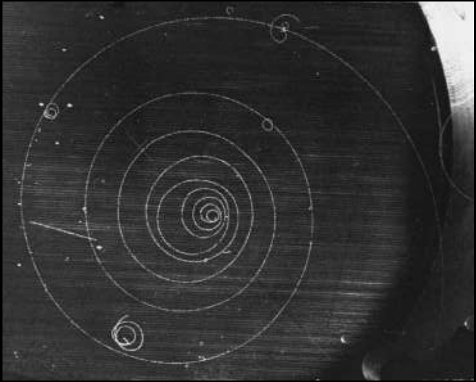
$$M = \frac{AQ}{Fz} \qquad M = Nm$$

$$m = \frac{A}{N_A} \qquad e = F/N_A$$

$$Q = Nze$$

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

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



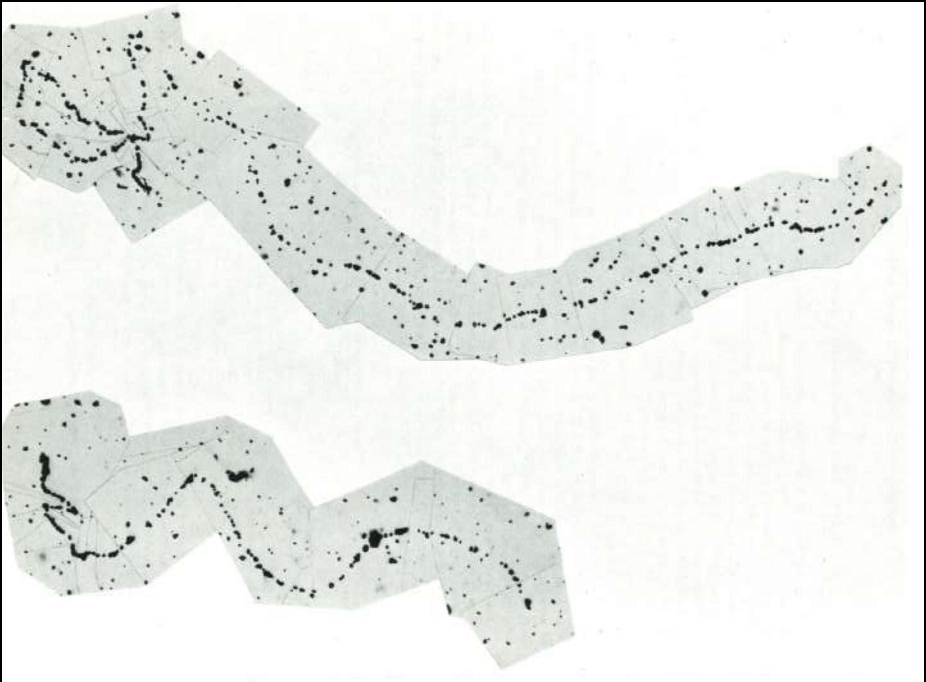
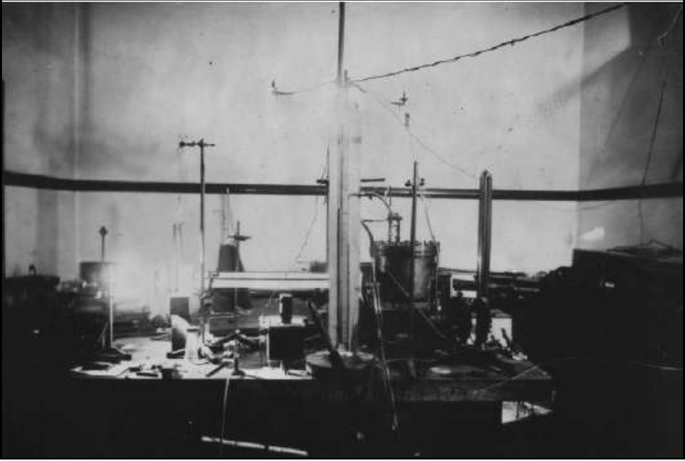
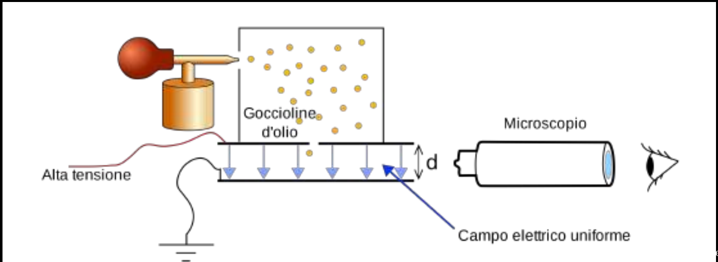


Image Credits: Cloudylabs





e Credits: Wikipedia

$$F = ma = mg \qquad F = eE$$

$$F_A \propto r$$

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

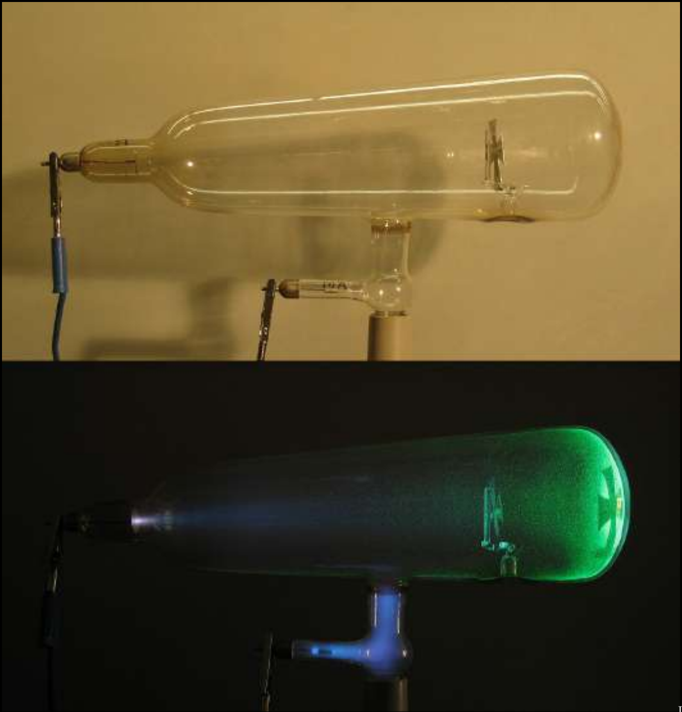


Image Credits: Wikipedia

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

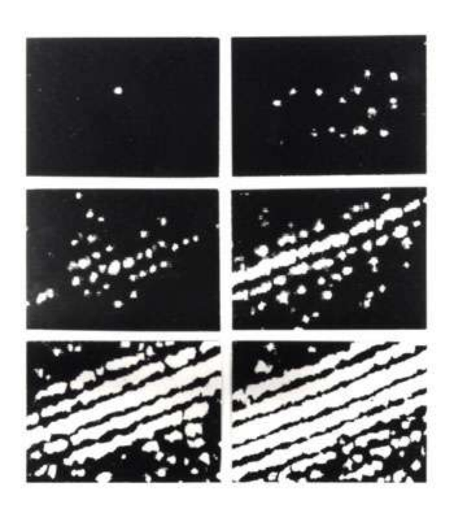


Image Credits: Physics World

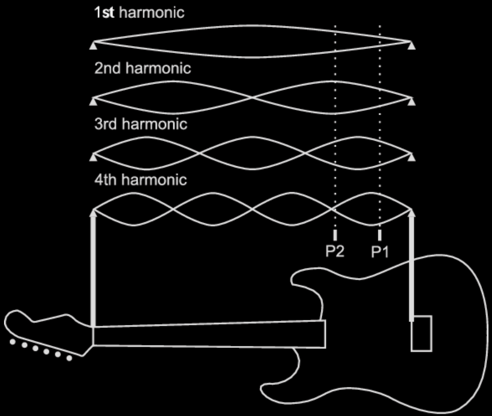


Image Credits: Journal of the Audio Engineering Society

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

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

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

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

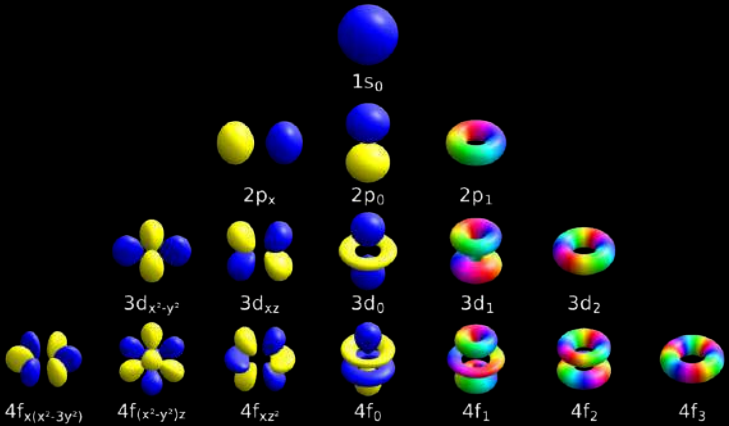


Image Credits: Wikipedia

Image Credits: Laboratori Nazionali di Frascati

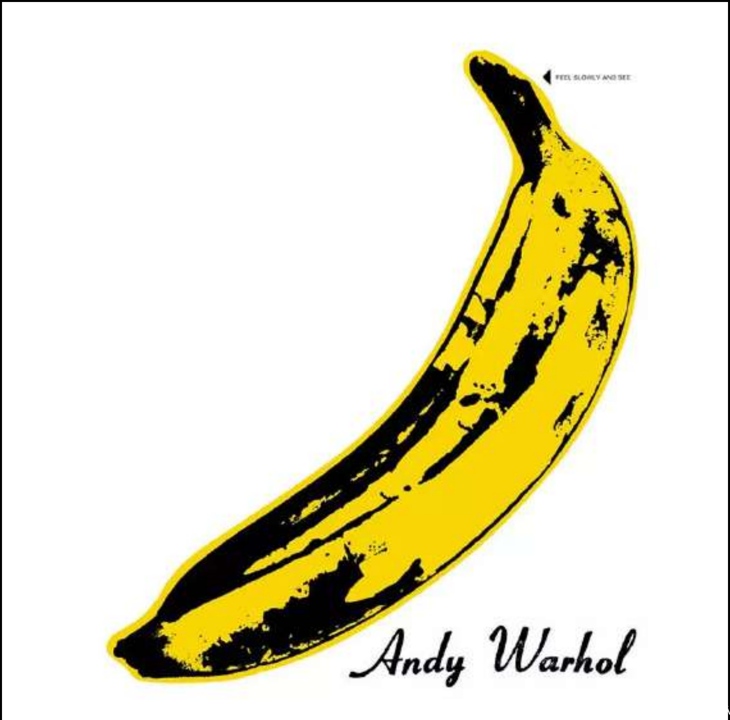
$$N = N_0 e^{-t/\tau}$$

$$\tau = 2.2\mu s$$

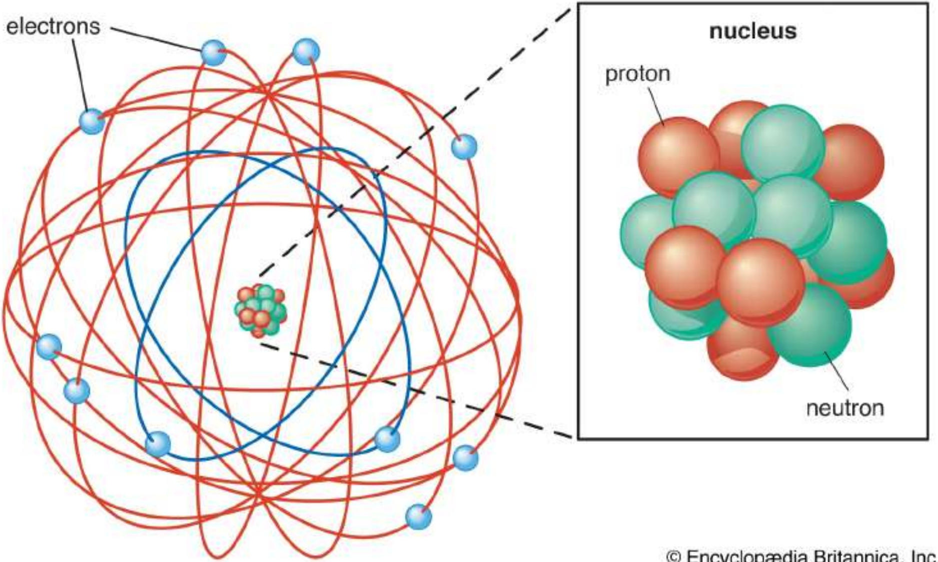
$$v = 99.5\% c$$

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

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



Velvet Underground


electrons
nucleus
proton
neutron

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.

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

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

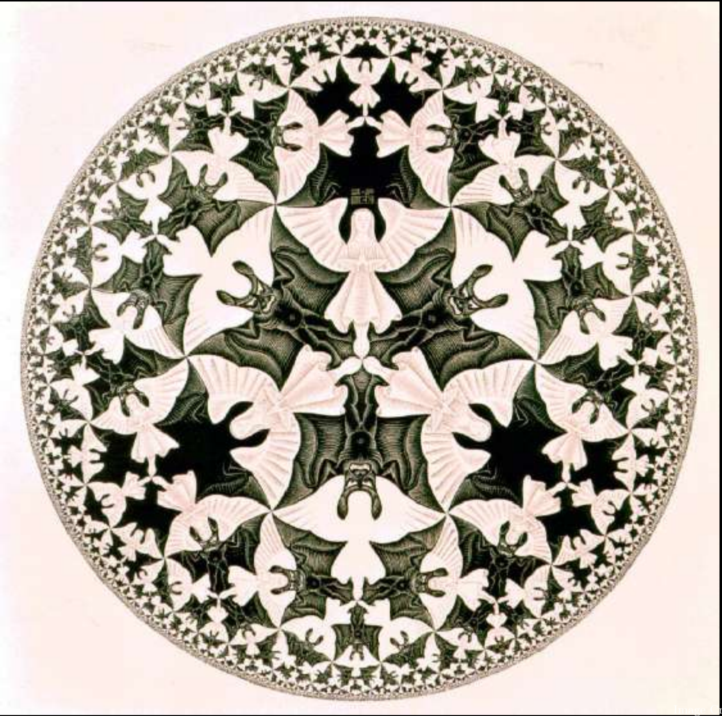


Image Credits: M. C. Escher

Image Credits: M. C. Escher

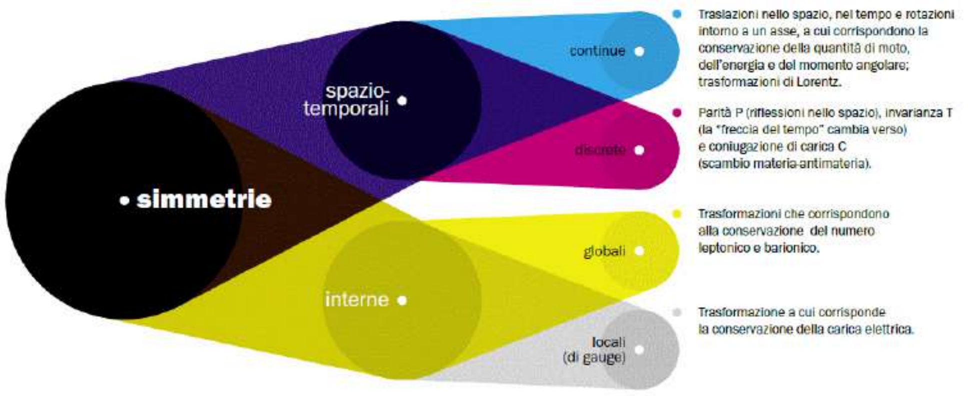


Image Credits: Simmetrie

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

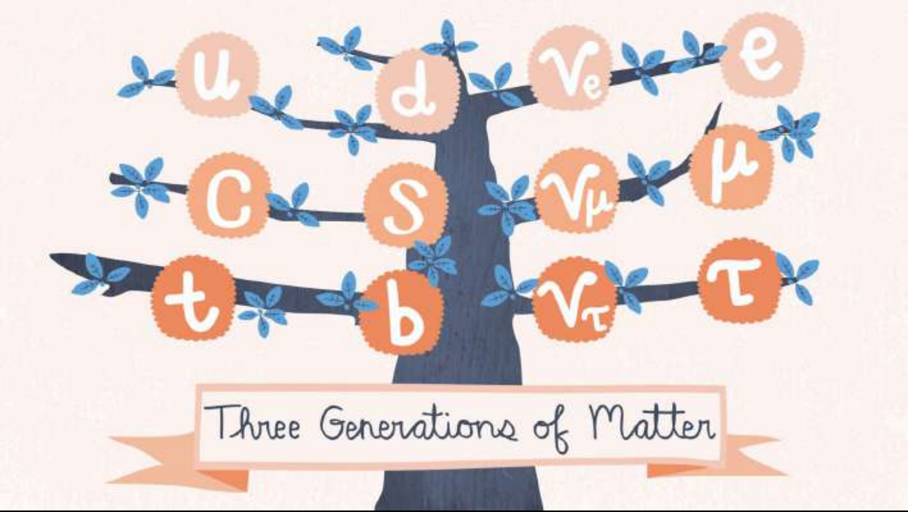
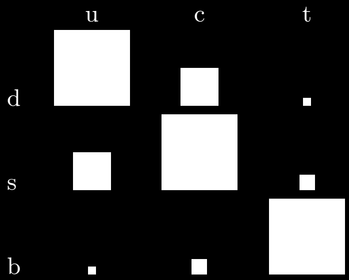
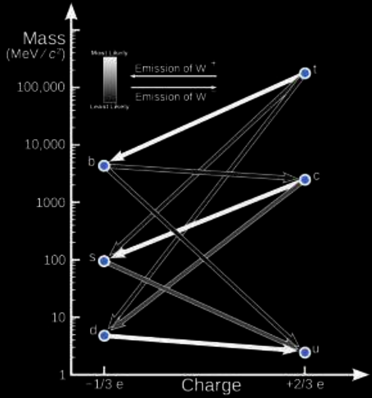


Image Credits: Symmetry Magazine


u
c
t
d
s
b


Mass
(MeV / c²)
100,000
10,000
1000
100
10
1
Emission of W+
Emission of W−
t
b
c
s
d
u
−1/3 e
Charge
+2/3 e