

Standard Model and beyond

in Colombia and in the World



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1803

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**XXIX CONGRESO
NACIONAL
vigesimonovenoo DE FÍSICA**

Focus on

Dark matter and neutrinos

In collaboration with

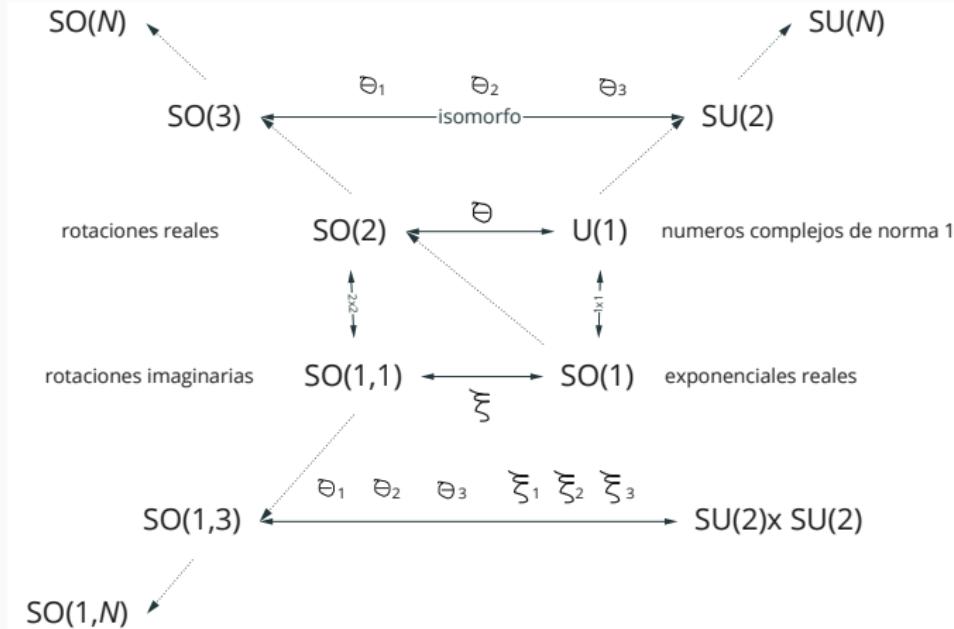
HEP Community in Colombia

Least Action

SO(3) scalar product

$$L = \frac{1}{2}m\mathbf{v}^2 - V(|\mathbf{r}|) = \frac{1}{2}m\mathbf{v} \cdot \mathbf{v} - V(|\mathbf{r}|)$$

Lie groups



$$U = \exp \left(i \sum_j T_j \theta^j \right), \quad (1)$$

where θ^j are the parameters of the transformation and T_j are the generators.

Consider the 1×1

$$K = -i, \quad (2)$$

which generates an element of dilaton group , SO(1), $R(\xi)$

$$\lambda(\xi) = e^\xi, \quad (3)$$

which are just the group of the real exponentials. Such a number can be transformed as

$$x \rightarrow x' = e^\xi x, \quad (4)$$

that corresponds to a boost by e^ξ . We can define the invariant scalar product just as the division of real numbers, such that

$$x \cdot y \rightarrow x' \cdot y' \equiv \frac{x'}{y'} = \frac{e^\xi x}{e^\xi y} = \frac{x}{y} = x \cdot y. \quad (5)$$

Queremos obtener una representación 2×2 del álgebra

$$K = \begin{pmatrix} 0 & -i \\ -i & 0 \end{pmatrix} \rightarrow K^2 = -\mathbf{1}, \quad (6)$$

que genera un elemento del grupo SO(1, 1) con *parámetro* ξ

$$\Lambda = \exp(i\xi K) = \begin{pmatrix} \cosh \xi & \sinh \xi \\ \sinh \xi & \cosh \xi \end{pmatrix}, . \quad (7)$$

La transformación de una coordenada temporaloide y otra espacialoide ($c = 1$)

$$\begin{pmatrix} t \\ x \end{pmatrix} = \begin{pmatrix} x^0 \\ x^1 \end{pmatrix} \rightarrow \begin{pmatrix} x'^0 \\ x'^1 \end{pmatrix} = \begin{pmatrix} \cosh \xi & \sinh \xi \\ \sinh \xi & \cosh \xi \end{pmatrix} \begin{pmatrix} x^0 \\ x^1 \end{pmatrix}$$

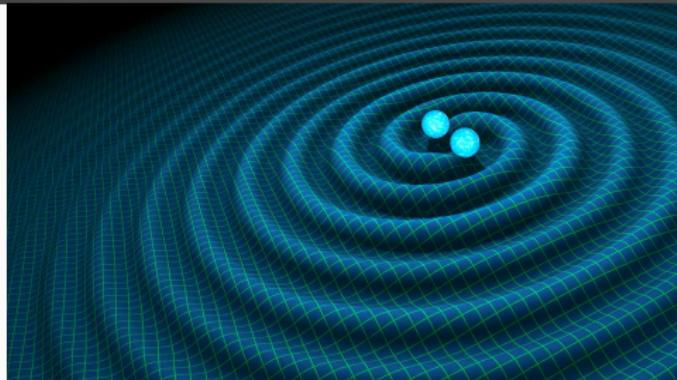
$$x'^\mu = \Lambda^\mu{}_\nu x^\nu, \quad \mu = 0, 1.$$

$$\cosh \xi = \gamma = \frac{1}{\sqrt{1 - v^2}}$$

Special: parameter ξ or v is constant, e.g, inertial system invariance: *Global* conservation of E and p (still action at a distance!)

General: parameter $\xi(t, x)$ or $v(t, x)$ is constant, e.g, accelerated system invariance: *Local* conservation of E and p

Inestability of binary particle systems



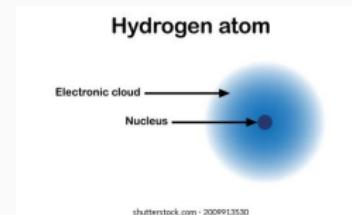
Gravitational wave discovery by LIGO



credits: science.org

Noether's paradigm → Lagrangian formulation of classical field theory

$U(1)$: From special θ to general $\theta(t, x)$



What is a *particle wavicle*?

<https://www.quantamagazine.org/what-is-a-particle-20201112/>

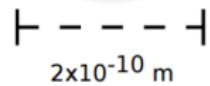
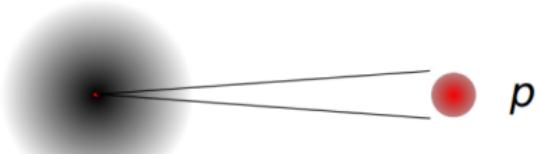
Is a “Quantum Excitation of a Field”



Is a “Irreducible Representation of a Group”



H

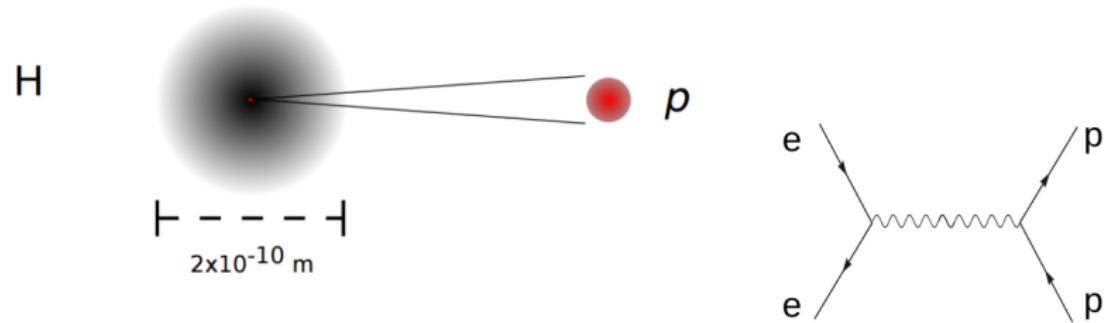


Interacción → Fuerza = $\Delta p/\Delta t$

Introducción

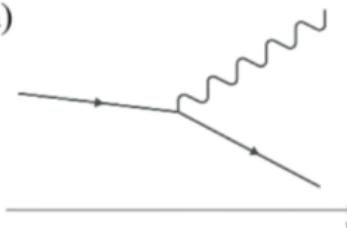
Campos de materia →

Campos de radiación ~~~~~

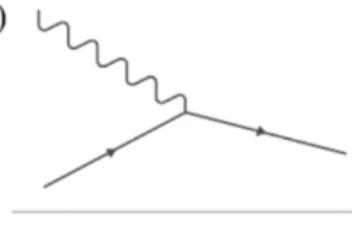


[doi:10.1088/1742-6596/1287/1/012045](https://doi.org/10.1088/1742-6596/1287/1/012045)

a)



b)



Emisión

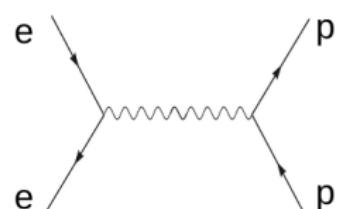
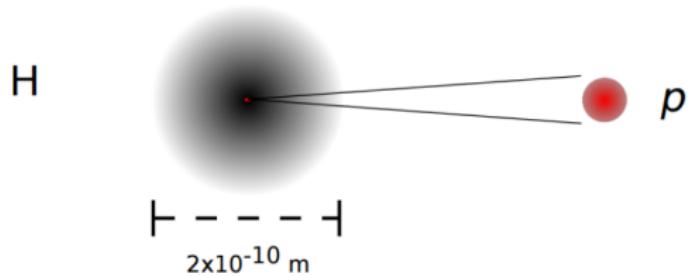
absorción

Interacción → Fuerza = $\Delta p/\Delta t$

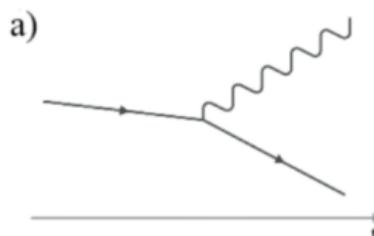
Introducción

Campos de materia →

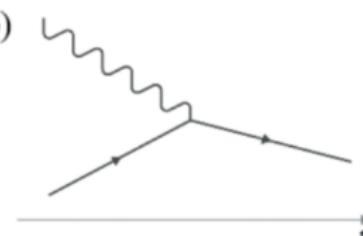
Campos de radiación ↗



[doi:10.1088/1742-6596/1287/1/012045](https://doi.org/10.1088/1742-6596/1287/1/012045)



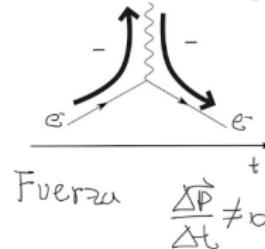
Emisión



absorción

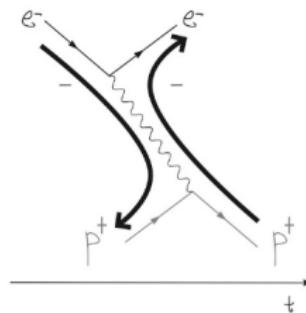
$$e^- \rightarrow e^{-iEt}$$
$$e^+ \rightarrow e^{-iE(-t)}$$

Single charge



$$(e^-)^* = e^+$$

↗ fotón neutro



Under a general Lorentz transformation we have for a **pure upperscript** 4-vector

$$A^\mu(x) \rightarrow A'^\mu(x) = \Lambda^\mu{}_\nu A^\nu(\Lambda^{-1}x), \quad (8)$$

where $\mu = 0, 1, 2, 3$. A **pure underscript** 4-vector is

$$\partial_\mu = \frac{\partial}{\partial x^\mu} = \left(\frac{\partial}{\partial t}, \frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z} \right) = (\partial_0, \nabla). \quad (9)$$

From $x'^\mu = \Lambda^\mu{}_\nu x^\nu$

$$\frac{1}{x'^\mu} = (\Lambda^{-1})^\nu{}_\mu \frac{1}{x^\nu}, \quad (10)$$

the transformation properties for a $\partial_\mu = \partial/\partial x^\mu$, are

$$\partial'_\mu = \partial_\nu (\Lambda^{-1})^\nu{}_\mu. \quad (11)$$

In this way, the invariant scalar product between the 4-vector field and the four-gradient is just

$$\partial_\mu A^\mu \rightarrow \partial'_\mu A'^\mu = \partial_\mu A^\mu. \quad (12)$$

Photon: Representation of the Poincaré Group which transform as a vector under $\text{SO}(1, 3)$

Name	Symbol	$\text{SO}(1, 3)$
Photon	A^μ	$\Lambda^\mu{}_\nu A^\nu$
4-gradient	∂_μ	$\partial_\nu (\Lambda^{-1})^\nu{}_\mu$

Table 1: Scalar products: $\partial_\mu A^\mu$, $A^\nu A_\nu$, $\partial_\mu \partial^\mu$

Name	Symbol	$\text{SU}(N)$
scalar N -plet	Ψ	$U\Psi$
scalar anti- N -plet	Ψ^\dagger	$\Psi^\dagger U^\dagger$

Table 2: Scalar products: $\Psi^\dagger \Psi$

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Table 2: Scalar products: $\Psi^\dagger \Psi$

Name	Symbol	$\text{SL}(2, C)$	$U(1)_Q$
e_L : electron left	ξ_α	$S_\alpha^\beta \xi_\beta$	$e^{i\theta} \xi_\alpha$
$(e_L)^\dagger$: positron right	$(\xi_\alpha)^\dagger = \xi_{\dot{\alpha}}^\dagger$	$\xi_{\dot{\beta}}^\dagger [S^\dagger]_{\dot{\alpha}}^{\dot{\beta}}$	$\xi_{\dot{\alpha}}^\dagger e^{-i\theta}$
e_R : electron right	$(\eta^\alpha)^\dagger = \eta^\dagger{}^{\dot{\alpha}}$	$[(S^{-1})^\dagger]_{\dot{\beta}}^{\dot{\alpha}} \eta^\dagger{}^{\dot{\beta}}$	$e^{i\theta} \eta^\dagger{}^{\dot{\alpha}}$
$(e_R)^\dagger$: positron left	η^α	$\eta^\beta [S^{-1}]_\beta^\alpha$	$e^{-i\theta} \eta^\alpha$

Table 3: electron **left**: $\text{SL}(2, C) \times U(1)$ inferior and positron **left**: $\text{SL}(2, C) \times U(1)$ superior

Scalar products

- $\mathcal{U}(1)$ Majorana scalars: $\xi^\alpha \xi_\alpha + \xi_{\dot{\alpha}}^\dagger \xi^{\dot{\alpha}}$, $\eta^\alpha \eta_\alpha + \eta_{\dot{\alpha}}^\dagger \eta^{\dot{\alpha}}$.
- Dirac scalar: $\eta^\alpha \xi_\alpha + \xi_{\dot{\alpha}}^\dagger \eta^{\dot{\alpha}}$.
- Tensor under subgroup $\text{SL}(2, C)$ but vector under $\text{SO}(1, 3)$: $S^{\dot{\alpha}}{}_{\dot{\beta}} \bar{\sigma}^{\mu}{}^{\dot{\beta}}{}^{\beta} S_\beta^\alpha = \Lambda^\mu{}_\nu \bar{\sigma}^\nu{}^{\dot{\alpha}}{}^{\alpha}$

$$\sigma^0 = \mathbb{1},$$

$$\bar{\sigma}^\mu = (\sigma^0, -\boldsymbol{\sigma}),$$

$$\sigma^\mu = (\sigma^0, \boldsymbol{\sigma}).$$

Name	Symbol	$\text{SL}(2, C)$	$U(1)_Q$
e_L : electron left	ξ_α	$S_\alpha^\beta \xi_\beta$	$e^{i\theta} \xi_\alpha$
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e_R : electron right	$(\eta^\alpha)^\dagger = \eta^\dagger{}_{\dot{\alpha}}$	$[(S^{-1})^\dagger]_{\dot{\beta}}^{\dot{\alpha}} \eta^\dagger{}_{\dot{\beta}}$	$e^{i\theta} \eta^\dagger{}_{\dot{\alpha}}$
$(e_R)^\dagger$: positron left	η^α	$\eta^\beta [S^{-1}]_\beta^\alpha$	$e^{-i\theta} \eta^\alpha$

Table 4: electron **left**: $\text{SL}(2, C) \times U(1)$ inferior and positron **left**: $\text{SL}(2, C) \times U(1)$ superior

General theory: QED $\rightarrow D_\mu = i\partial_\mu - ieA_\mu$, $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$



$$\xi^\alpha \rightarrow \xi'^\alpha = e^{i\theta(x)} \xi^\alpha \quad \eta_\alpha \rightarrow \eta'_\alpha = e^{-i\theta(x)} \eta_\alpha$$

$$D_\mu \xi^\alpha \rightarrow (D_\mu \xi^\alpha)' = e^{i\theta(x)} D_\mu \xi^\alpha \quad D_\mu \eta_\alpha \rightarrow (D_\mu \eta_\alpha)' = e^{-i\theta(x)} D_\mu \eta_\alpha$$

$$\mathcal{L} = i\xi_{\dot{\alpha}}^\dagger \bar{\sigma}^\mu{}^{\dot{\alpha}\alpha} D_\mu \xi_\alpha + i\eta^\alpha \sigma^\mu_{\alpha\dot{\alpha}} D_\mu \eta^\dagger{}_{\dot{\alpha}} - m \left(\eta^\alpha \xi_\alpha + \xi_{\dot{\alpha}}^\dagger \eta^\dagger{}_{\dot{\alpha}} \right) - \frac{1}{4} F^{\mu\nu} F_{\mu\nu}$$

Name	Symbol	$\text{SL}(2, C)$	$U(1)_Q$
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Table 4: electron **left**: $\text{SL}(2, C) \times U(1)$ inferior and positron **left**: $\text{SL}(2, C) \times U(1)$ superior

General theory: QED $\rightarrow D_\mu = i\partial_\mu - ieA_\mu$, $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$.

Dirac spinor

$$\begin{aligned}\xi^\alpha &\rightarrow \xi'^\alpha = e^{i\theta(x)} \xi^\alpha & \eta_\alpha &\rightarrow \eta'_\alpha = e^{-i\theta(x)} \eta_\alpha \\ D_\mu \xi^\alpha &\rightarrow (D_\mu \xi^\alpha)' = e^{i\theta(x)} D_\mu \xi^\alpha & D_\mu \eta_\alpha &\rightarrow (D_\mu \eta_\alpha)' = e^{-i\theta(x)} D_\mu \eta_\alpha\end{aligned}$$

$$\begin{aligned}\mathcal{L} &= i\xi_{\dot{\alpha}}^\dagger \bar{\sigma}^\mu{}^{\dot{\alpha}\alpha} D_\mu \xi_\alpha + i\eta^\alpha \sigma^\mu_{\alpha\dot{\alpha}} D_\mu \eta^\dagger{}^{\dot{\alpha}} - m \left(\eta^\alpha \xi_\alpha + \xi_{\dot{\alpha}}^\dagger \eta^\dagger{}^{\dot{\alpha}} \right) - \frac{1}{4} F^{\mu\nu} F_{\mu\nu} \\ \mathcal{L} &= i\bar{\psi} \gamma^\mu D_\mu \psi - m \bar{\psi} \psi - \frac{1}{4} F^{\mu\nu} F_{\mu\nu}.\end{aligned}$$

$$\begin{aligned}\psi &= \begin{pmatrix} e_L \\ e_R \end{pmatrix} \\ \gamma^\mu &= \begin{pmatrix} 0 & \sigma^\mu \\ \bar{\sigma}^\mu & 0 \end{pmatrix} \\ \bar{\psi} &= \psi^\dagger \gamma^0.\end{aligned}$$

$$\text{SU}(2)_L \rightarrow D_\mu = \mathbf{1} \partial_\mu - ig_2 \frac{\tau_i}{2} W_\mu^i \quad : 17 \text{ years later... (stages of grief} \rightarrow 1967)$$

Not mass, not charge

Field	Lorentz	$\text{SU}(2)_L$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	2

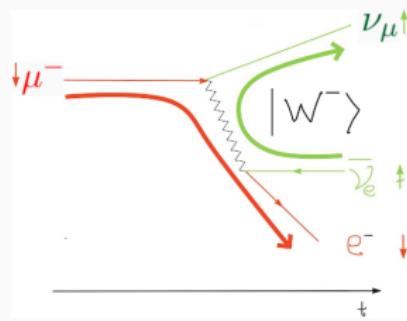
Denial

$$|W^0\rangle = |\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle \quad \begin{array}{c} \nearrow \\ \swarrow \end{array}$$

$$|W^+\rangle \quad |\downarrow\downarrow\rangle \quad \begin{array}{c} \nearrow \\ \nearrow \end{array}$$

$$|W^-\rangle \quad |\uparrow\downarrow\rangle \quad \begin{array}{c} \swarrow \\ \swarrow \end{array}$$

$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \frac{1}{4} W_{\mu\nu}^i W_i^{\mu\nu}$$



$SU(2)_L \times U(1)_Y \rightarrow D_\mu = \mathbf{1} \partial_\mu - ig_2 \frac{\tau_i}{2} W_\mu^i - ig_1 B_\mu$: 17 years later... (stages of grief \rightarrow 1967)

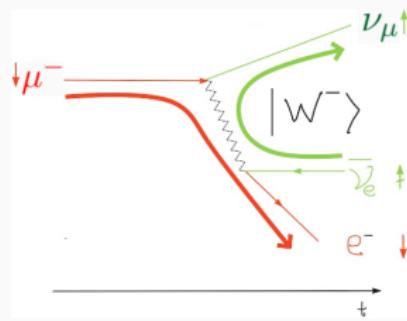
Not mass, hypercharge,

Field	Lorentz	$SU(2)_L$	$U(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	2	-1/2

Denial

$$\begin{aligned} |W^0\rangle &= |\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle & \text{green arrows} \\ |W^+\rangle & \quad |\downarrow\uparrow\rangle & \text{red arrow} \\ |W^-\rangle & \quad |\uparrow\downarrow\rangle & \text{green arrow} \end{aligned}$$

$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \frac{1}{4} W_{\mu\nu}^i W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$$

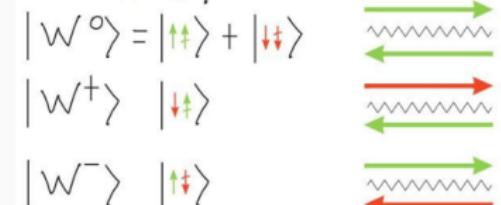


$SU(2)_L \times U(1)_Y \rightarrow D_\mu = \mathbf{1} \partial_\mu - ig_2 \frac{\tau_i}{2} W_\mu^i - ig_1 B_\mu$: 17 years later... (stages of grief \rightarrow 1967)

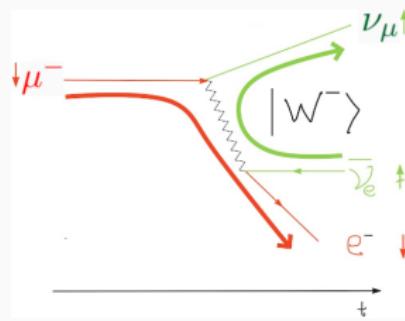
Not mass, hypercharge, not Dirac

Field	Lorentz	$SU(2)_L$	$U(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	$\mathbf{2}$	$-1/2$
$(e_R)^\dagger$	η^α	$\mathbf{1}$	-1

Denial



$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \frac{1}{4} W_{\mu\nu}^i W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R$$

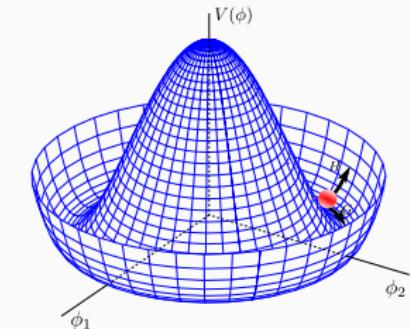


$SU(2)_L \times U(1)_Y \rightarrow D_\mu = \mathbf{1} \partial_\mu - ig_2 \frac{\tau_i}{2} W_\mu^i - ig_1 B_\mu : 17$ years later... (stages of grief $\rightarrow 1967$)

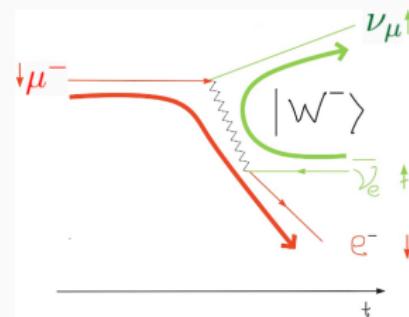
Higgs mechanism: tachyonic mass $\mu^2 < 0$, and condensate

Contempt

Field	Lorentz	$SU(2)_L$	$U(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	2	$-1/2$
$(e_R)^\dagger$	η^α	1	-1
$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \left[\frac{H(x) + v}{\sqrt{2}} \right] \exp \left[i \frac{\tau^i}{2} G_i(x) \right]$	-	2	$1/2$



$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \tfrac{1}{4} W_{\mu\nu}^i W_i^{\mu\nu} - \tfrac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + (e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi^\dagger \Phi)^2$$



Higgs mechanism: tachyonic mass $\mu^2 < 0$, and condensate

Field	Lorentz	$SU(2)_L$	$U(1)_Y$	Contempt
$L = \begin{pmatrix} \nu_L \\ e_L \\ (e_R)^\dagger \end{pmatrix}$	ξ_α	$\mathbf{2}$	$-1/2$	
$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \left[\frac{H(x) + v}{\sqrt{2}} \right] \exp \left[i \frac{\tau^i}{2} G_i(x) \right]$	η^α	$\mathbf{1}$	-1	
	-	$\mathbf{2}$	$1/2$	$\begin{pmatrix} W_\mu^3 \\ B_\mu \end{pmatrix} = \begin{pmatrix} \cos \theta_W & \sin \theta_W \\ -\sin \theta_W & \cos \theta_W \end{pmatrix} \begin{pmatrix} Z_\mu \\ A_\mu \end{pmatrix},$

$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \frac{1}{4} W_{\mu\nu}^i W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + (e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi^\dagger \Phi)^2$$

$$\Phi \rightarrow \Phi' = \exp \left[i \frac{\tau^i}{2} \theta_i(x) \right] \Phi = \frac{1}{\sqrt{2}} [H(x) + v]$$

$$\mathcal{L} = i\bar{\psi} \gamma^\mu \partial_\mu \psi - m_e \bar{\psi} \psi - i(\nu_L)^\dagger \bar{\sigma}^\mu \partial_\mu \nu_L + \frac{1}{2} \partial^\mu H \partial_\mu H + \frac{e}{\cos \theta_W \sin \theta_W} \bar{\nu}_L \nu_L Z_\mu + \dots$$

$$-\frac{1}{2} m_H^2 H^2 \left(1 + \frac{H}{v} + \frac{H^2}{4v^2} \right) + \left(m_W^2 W^\mu - W_\mu^+ + \frac{1}{2} m_Z^2 Z^\mu Z_\mu \right) \left(1 + 2 \frac{H}{v} + \frac{H^2}{v^2} \right) + \frac{m_e}{v} \bar{\psi} \psi H$$

$SU(2)_L \times U(1)_Y \rightarrow D_\mu = 1\partial_\mu - ig_2 \frac{\tau_i}{2} W_\mu^i - ig_1 B_\mu$: 21 years later... (stages of grief \rightarrow 1971)

Z and W phenomenology and discovery

Field	Lorentz	$SU(2)_L$	$U(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	2	$-1/2$
$(e_R)^\dagger$	η^α	1	-1
$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \left[\frac{H(x) + v}{\sqrt{2}} \right] \exp \left[i \frac{\tau^i}{2} G_i(x) \right]$	-	2	$1/2$

Bargaining



$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \frac{1}{4} W_{\mu\nu}^i W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + (e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi^\dagger \Phi)^2$$

$$\Phi \rightarrow \Phi' = \exp \left[i \frac{\tau^i}{2} \theta_i(x) \right] \Phi = \frac{1}{\sqrt{2}} [H(x) + v]$$

$$\mathcal{L} = \bar{\psi} \gamma^\mu \partial_\mu \psi - m_e \bar{\psi} \psi - i(\nu_L)^\dagger \bar{\sigma}^\mu \partial_\mu \nu_L + \frac{1}{2} \partial^\mu H \partial_\mu H + \frac{e}{\cos \theta_W \sin \theta_W} \bar{\nu}_L \nu_L Z_\mu + \dots$$

$$- \frac{1}{2} m_H^2 H^2 \left(1 + \frac{H}{v} + \frac{H^2}{4v^2} \right) + \left(m_W^2 W^\mu - W_\mu^+ + \frac{1}{2} m_Z^2 Z^\mu Z_\mu \right) \left(1 + 2 \frac{H}{v} + \frac{H^2}{v^2} \right) + \frac{m_e}{v} \bar{\psi} \psi H$$

$SU(2)_L \times U(1)_Y \rightarrow D_\mu = \mathbf{1} \partial_\mu - ig_2 \frac{\tau_i}{2} W_\mu^i - ig_1 B_\mu : 32$ years later... (stages of grief $\rightarrow 1982$)

Hierarchy problem

Field	Lorentz	$SU(2)_L$	$U(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	2	$-1/2$
$(e_R)^\dagger$	η^α	1	-1
$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \left[\frac{H(x) + v}{\sqrt{2}} \right] \exp \left[i \frac{\tau^i}{2} G_i(x) \right]$	-	2	$1/2$

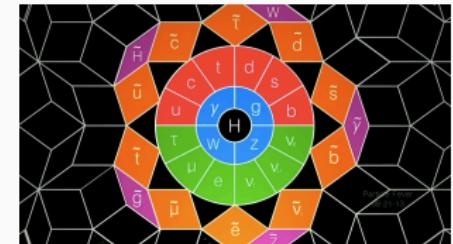
$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \frac{1}{4} W_{\mu\nu}^i W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + (e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi^\dagger \Phi)^2$$

$$\Phi \rightarrow \Phi' = \exp \left[i \frac{\tau^i}{2} \theta_i(x) \right] \Phi = \frac{1}{\sqrt{2}} [H(x) + v]$$

$$\mathcal{L} = i\bar{\psi} \gamma^\mu \partial_\mu \psi - m_e \bar{\psi} \psi - i(\nu_L)^\dagger \bar{\sigma}^\mu \partial_\mu \nu_L + \frac{1}{2} \partial^\mu H \partial_\mu H + \frac{e}{\cos \theta_W \sin \theta_W} \bar{\nu}_L \nu_L Z_\mu + \dots$$

$$-\frac{1}{2} m_H^2 H^2 \left(1 + \frac{H}{v} + \frac{H^2}{4v^2} \right) + \left(m_W^2 W^{\mu-} W_\mu^+ + \frac{1}{2} m_Z^2 Z^\mu Z_\mu \right) \left(1 + 2 \frac{H}{v} + \frac{H^2}{v^2} \right) + \frac{m_e}{v} \bar{\psi} \psi H$$

Depression



credit: quantumdiaries.org

$SU(2)_L \times U(1)_Y \rightarrow D_\mu = 1\partial_\mu - ig_2 \frac{\tau_i}{2} W_\mu^i - ig_1 B_\mu$: 62 years later... (stages of grief \rightarrow 2012)

Higgs discovery!

Field	Lorentz	$SU(2)_L$	$U(1)_Y$
$L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	ξ_α	2	$-1/2$
$(e_R)^\dagger$	η^α	1	-1
$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \left[\frac{H(x) + v}{\sqrt{2}} \right] \exp \left[i \frac{\tau^i}{2} G_i(x) \right]$	-	2	$1/2$

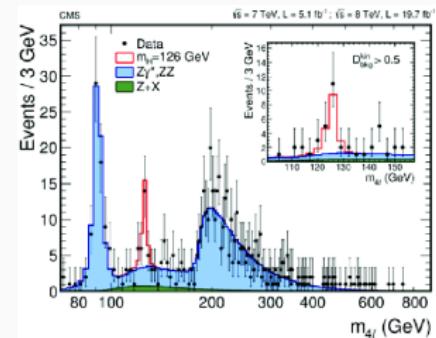
$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \frac{1}{4} W_{\mu\nu}^i W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + (e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi^\dagger \Phi)^2$$

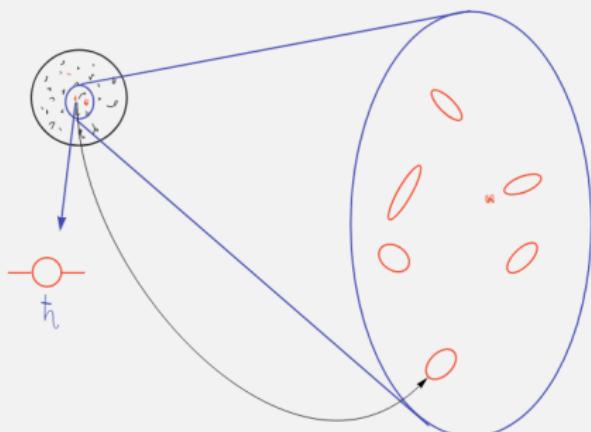
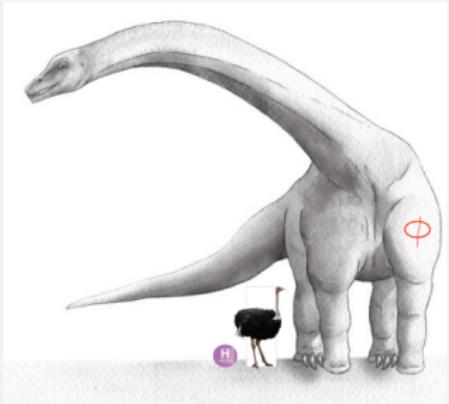
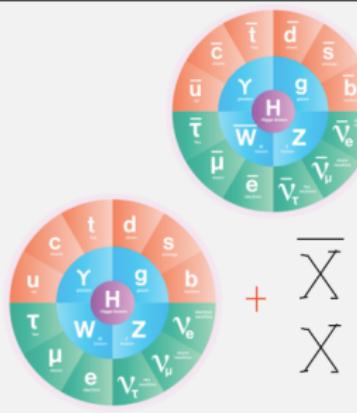
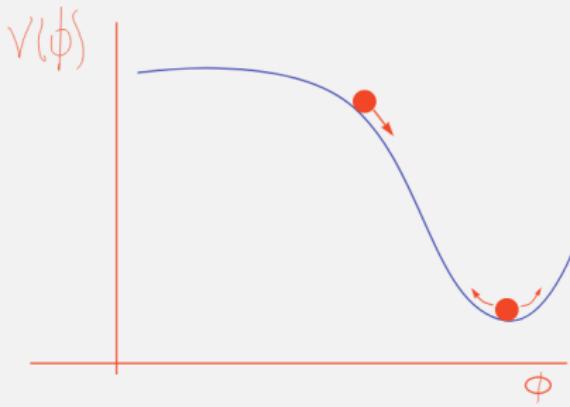
$$\Phi \rightarrow \Phi' = \exp \left[i \frac{\tau^i}{2} \theta_i(x) \right] \Phi = \frac{1}{\sqrt{2}} [H(x) + v]$$

$$\mathcal{L} = i\bar{\psi} \gamma^\mu \partial_\mu \psi - m_e \bar{\psi} \psi - i(\nu_L)^\dagger \bar{\sigma}^\mu \partial_\mu \nu_L + \frac{1}{2} \partial^\mu H \partial_\mu H + \frac{e}{\cos \theta_W \sin \theta_W} \bar{\nu}_L \nu_L Z_\mu + \dots$$

$$-\frac{1}{2} m_H^2 H^2 \left(1 + \frac{H}{v} + \frac{H^2}{4v^2} \right) + \left(m_W^2 W^{\mu-} W_\mu^+ + \frac{1}{2} m_Z^2 Z^\mu Z_\mu \right) \left(1 + 2 \frac{H}{v} + \frac{H^2}{v^2} \right) + \frac{m_e}{v} \bar{\psi} \psi H$$

Acceptance





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Jacobus Kapteyn - Wikipedia

Prof Jacobus Cornelius Kapteyn FRS FRSE LLD (19 January 1851 – 18 June 1922) was a Dutch astronomer. He carried out extensive studies of the Milky Way and was the discoverer of evidence for galactic rotation. Kapteyn was also among the first to suggest ...



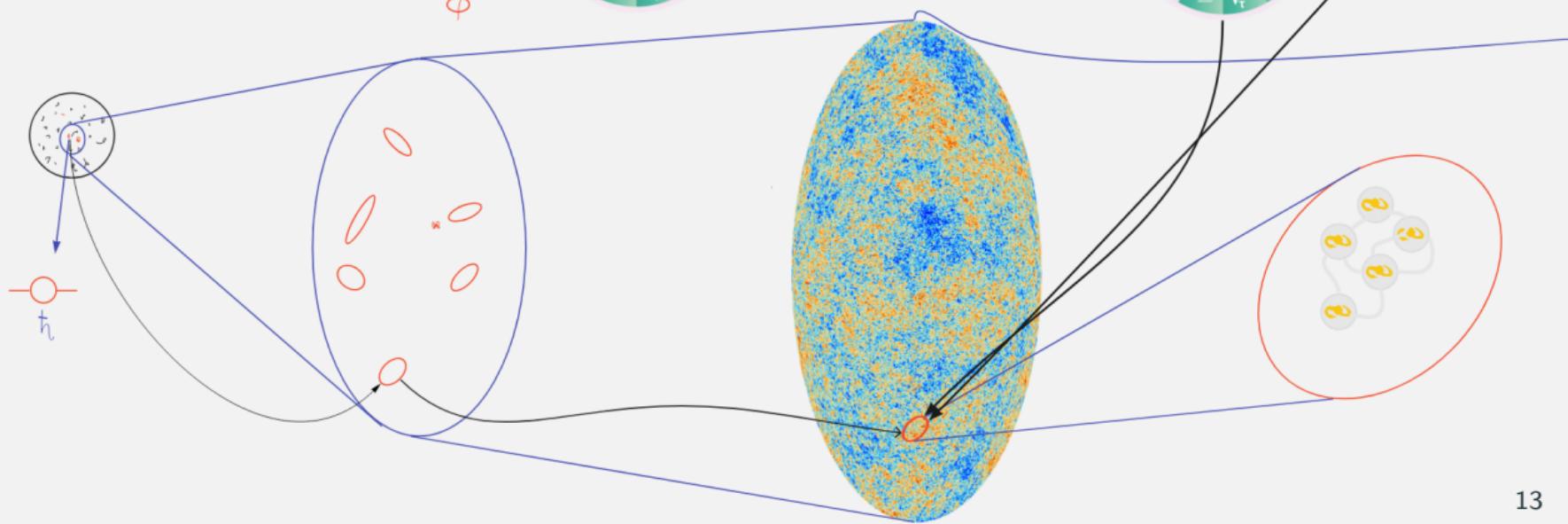
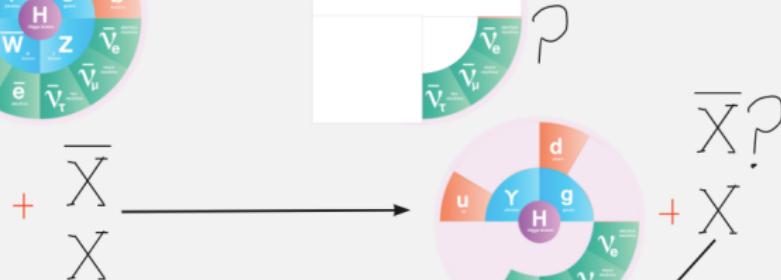
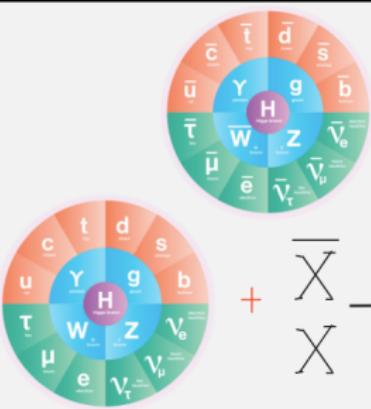
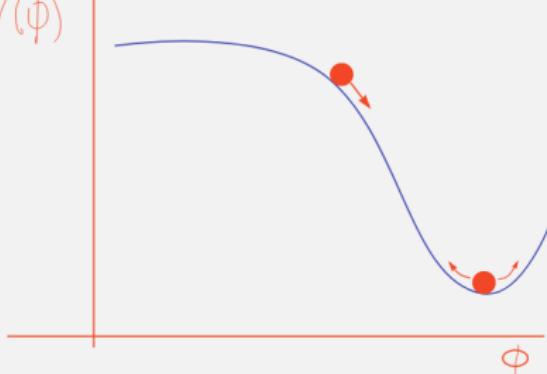
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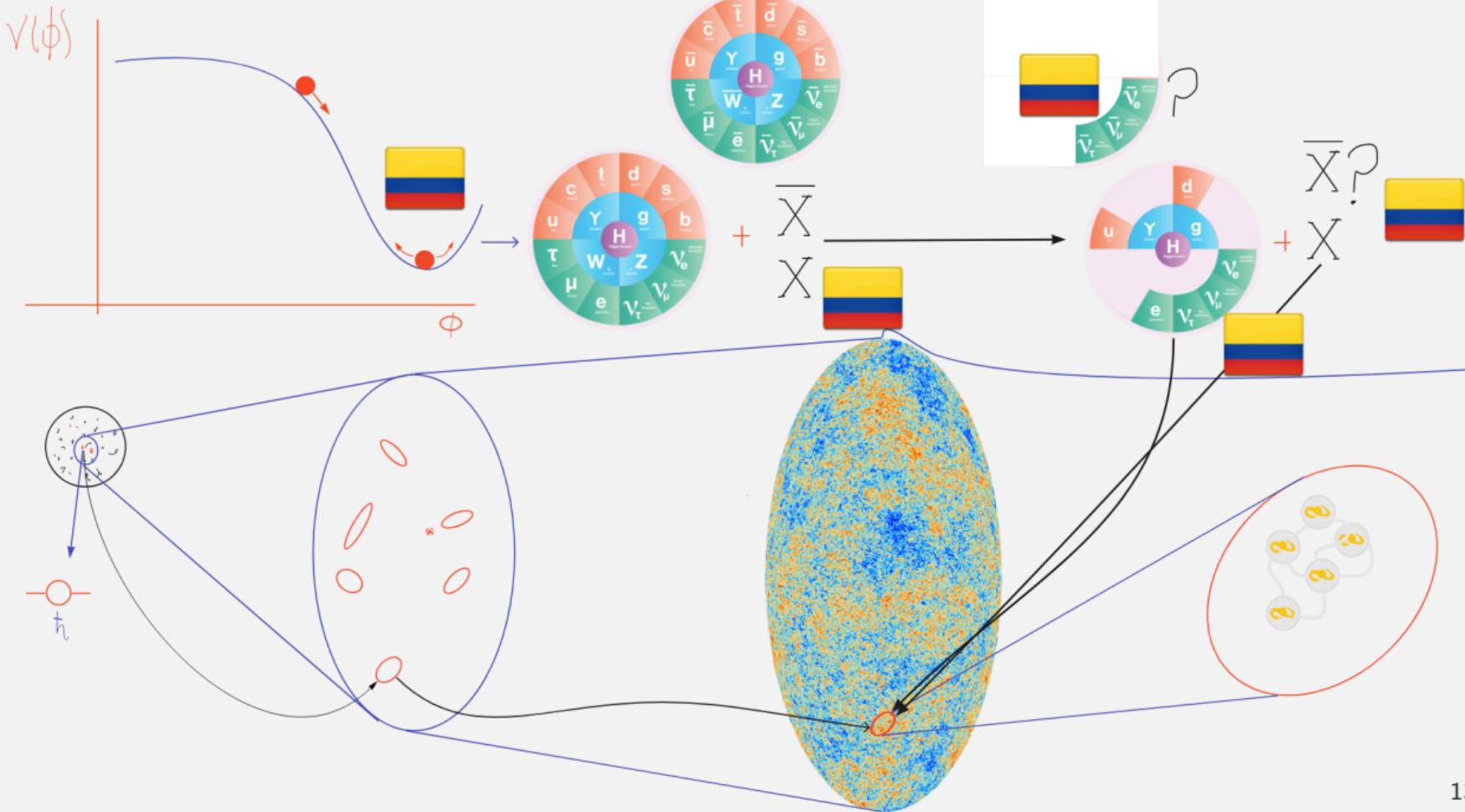
Fritz Zwicky - Wikipedia

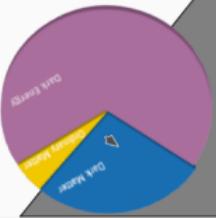
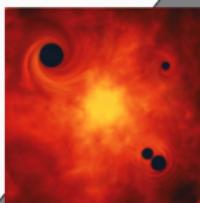
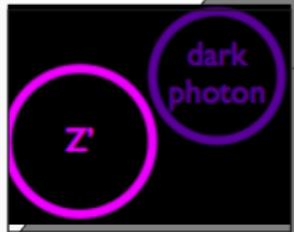
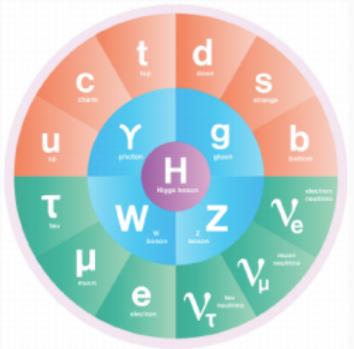
Fritz Zwicky (; German: ; February 14, 1898 – February 8, 1974) was a Swiss astronomer. He worked most of his life at the California Institute of Technology in the United States of America, where he made many important contributions in theoretical and o...

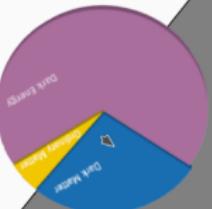
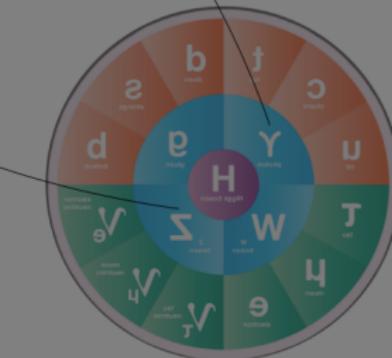
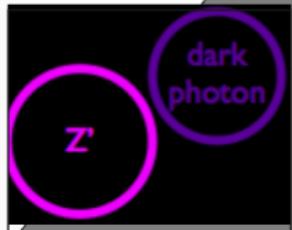
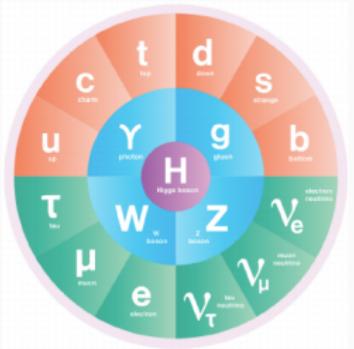


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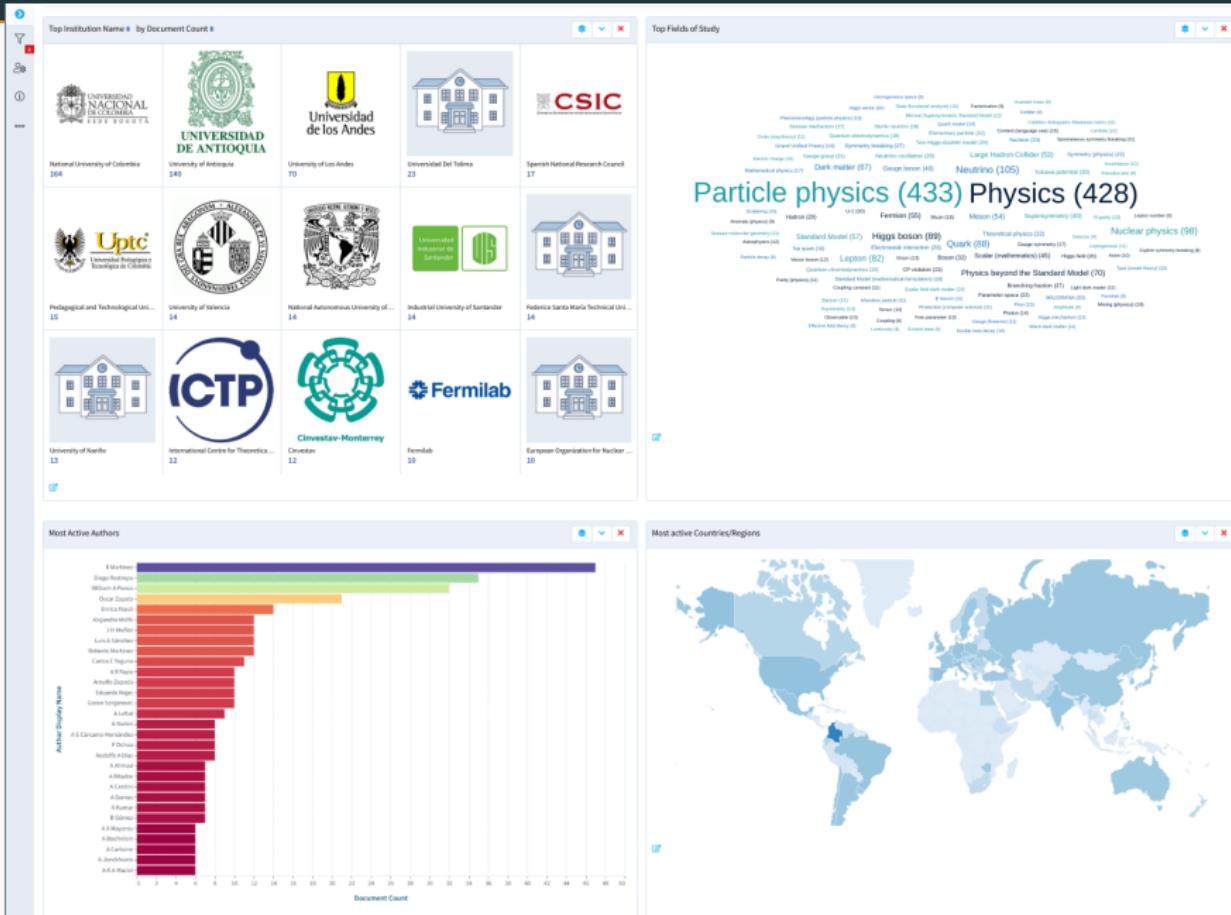








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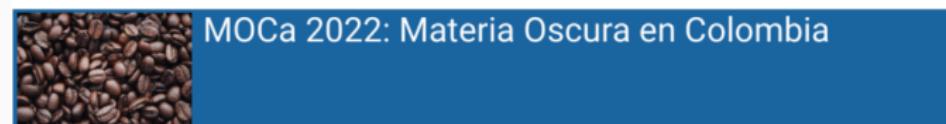


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arXiv:2104.06852v1 [hep-ex] 14 Apr 2021

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GA Mejía Cortés - Revista Colombiana de Física, 2014 - fisica.udea.edu.co

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Conclusiones

La consolidación experimental del modelo estándar abre nuevos retos a la enseñanza de la física contemporánea en los pregrados, donde se debería hacer más énfasis en las propiedades generales de las teorías clásicas de campos a la luz de los teoremas de Noether.

