

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

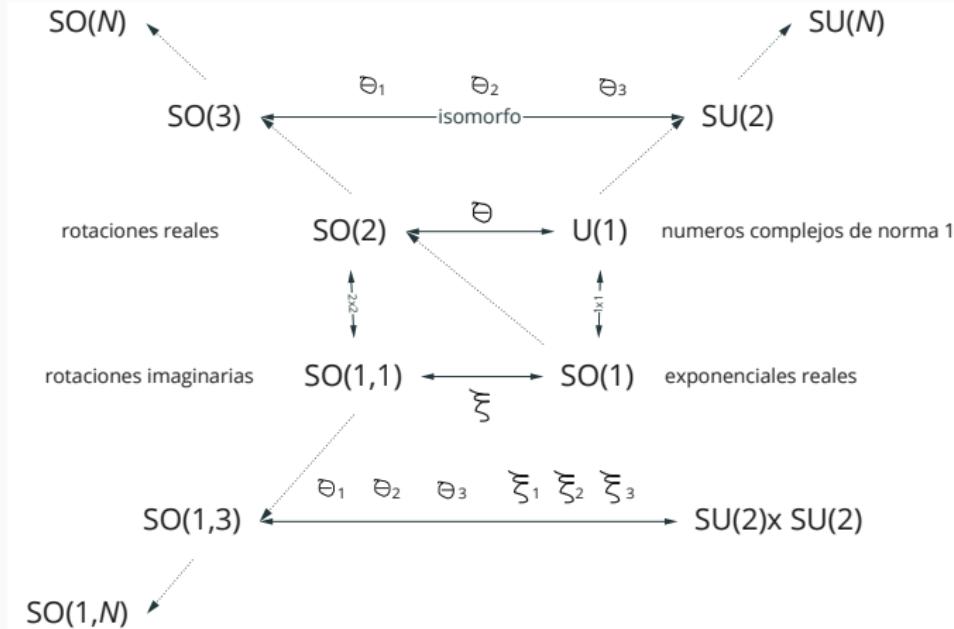
HEP Community in Colombia

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 ($c = 1$)

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

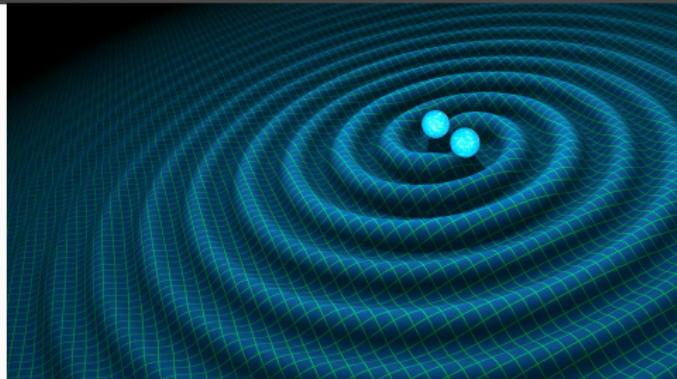
$$x'^\mu = \Lambda^\mu{}_\nu x^\nu, \quad \mu = 0, 1.$$

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

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



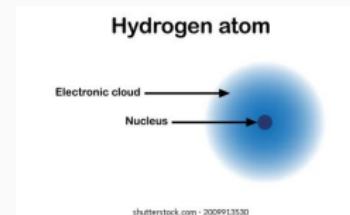
Gravitational wave discovery by LIGO



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/>

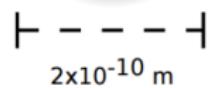
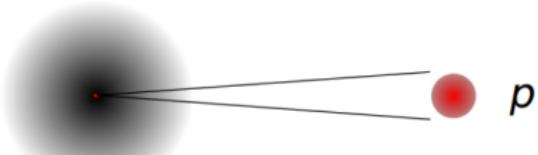
Is a “Quantum Excitation of a Field”



Is a “Irreducible Representation of a Group”



H

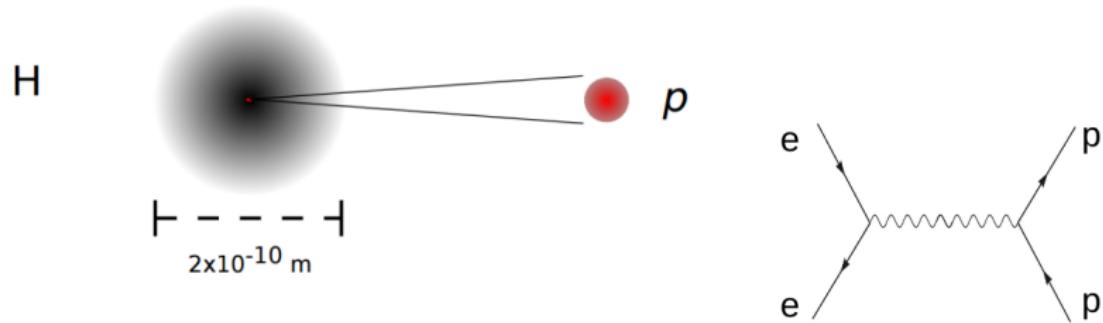


Interacción → Fuerza = $\Delta p/\Delta t$

Introducción

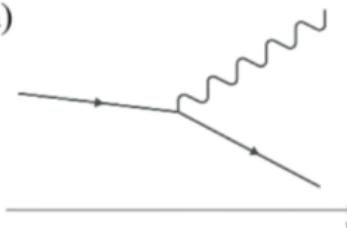
Campos de materia →

Campos de radiación ~~~~~



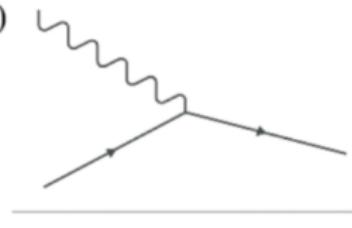
[doi:10.1088/1742-6596/1287/1/012045](https://doi.org/10.1088/1742-6596/1287/1/012045)

a)



Emisión

b)



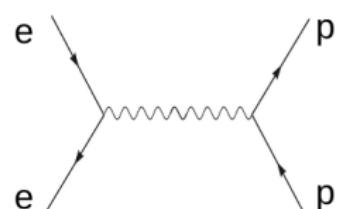
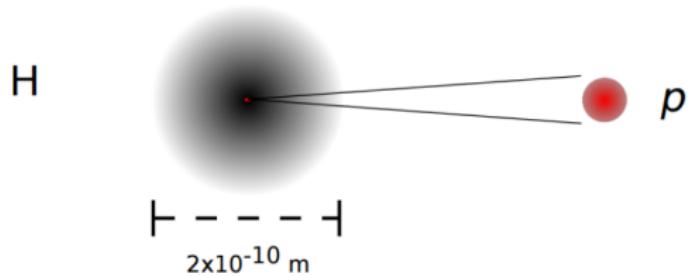
absorción

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

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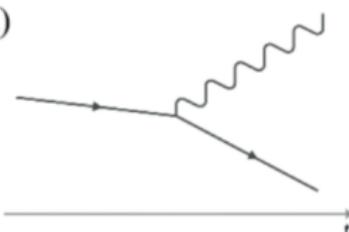
Campos de materia →

Campos de radiación ↗

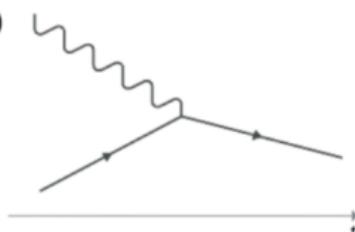


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a)



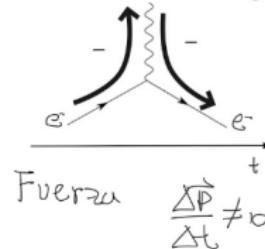
b)



$$e^- \rightarrow e^{-iEt}$$

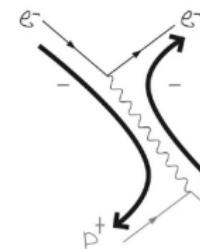
$$e^+ \rightarrow e^{-iE(-t)}$$

Single charge



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

↗ fotón neutro



Emisión

absorción

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: $\Psi^\dagger \Psi$

Photon: $\hat{p} \oplus \text{SO}(1, 3) = i\partial^\mu \oplus \text{SO}(1, 3) \rightarrow iD^\mu \oplus \text{SO}(1, 3)$

Name	Symbol	$\text{SO}(1, 3)$
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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	$\text{SL}(2, C)$	$U(1)_Q$
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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 $\rightarrow D_\mu = i\partial_\mu - ieA_\mu$, $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$



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

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

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

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Dirac spinor

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

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

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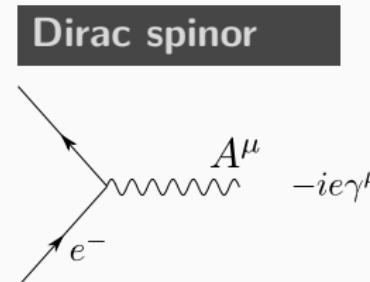
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$$\mathcal{L} = \bar{n} \psi \gamma^\mu D_\mu \psi - m \bar{\psi} \psi - \frac{1}{4} F^{\mu\nu} F_{\mu\nu} \rightarrow e \bar{\psi} \gamma^\mu \psi A_\mu$$



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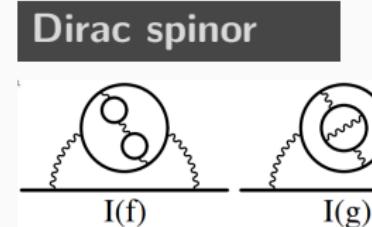
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$$\text{SU}(2)_L \rightarrow D_\mu = \mathbf{1} \partial_\mu - ig_2 \frac{\tau_i}{2} W_\mu^i \quad : 17 \text{ years later... (stages of grief} \rightarrow 1967)$$

Not mass, not charge

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

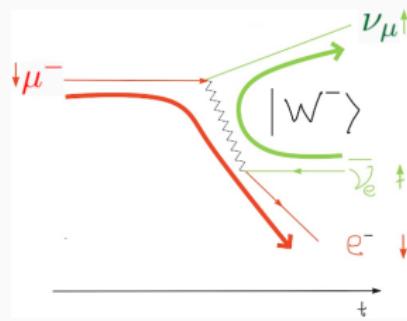
Denial

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

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

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

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

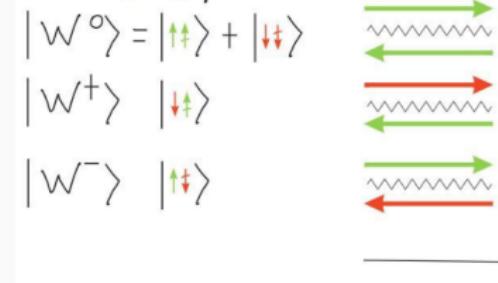


$SU(2)_L \times U(1)_Y \rightarrow D_\mu = \mathbf{1} \partial_\mu - ig_2 \frac{\tau_i}{2} W_\mu^i - ig_1 B_\mu$: 17 years later... (stages of grief \rightarrow 1967)

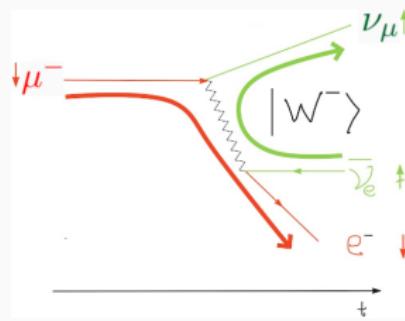
Not mass, hypercharge,

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

Denial



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

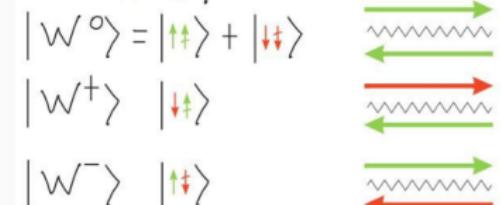


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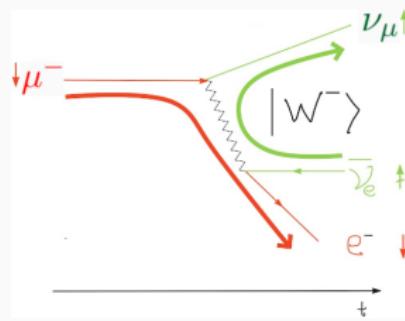
Not mass, hypercharge, not Dirac

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



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

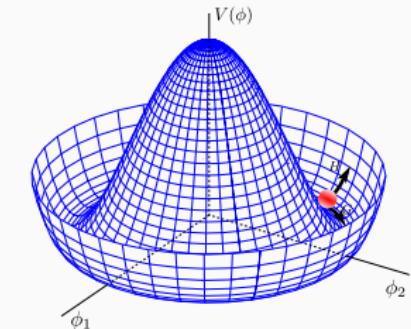


$SU(2)_L \times U(1)_Y \rightarrow D_\mu = \mathbf{1} \partial_\mu - ig_2 \frac{\tau_i}{2} W_\mu^i - ig_1 B_\mu : 17$ years later... (stages of grief $\rightarrow 1967$)

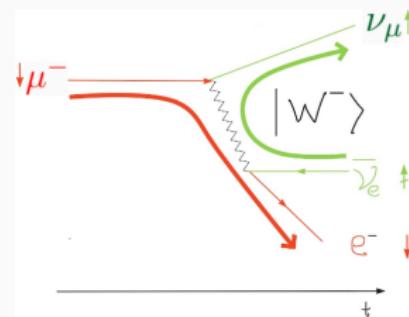
Higgs mechanism: tachyonic mass $\mu^2 < 0$, and condensate

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
$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \left[\frac{H(x)+\nu}{\sqrt{2}} \right] \exp \left[i \frac{\tau^i}{2} G_i(x) \right]$	-	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	$\mathbf{2}$	$-1/2$
$(e_R)^\dagger$	η^α	$\mathbf{1}$	-1
$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \left[\frac{H(x) + v}{\sqrt{2}} \right] \exp \left[i \frac{\tau^i}{2} G_i(x) \right]$	-	$\mathbf{2}$	$1/2$

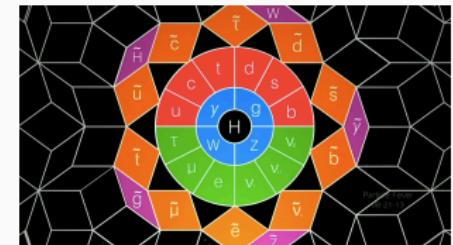
$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \frac{1}{4} W_{\mu\nu}^i W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + (e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi^\dagger \Phi)^2$$

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

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

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

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	$1/2$

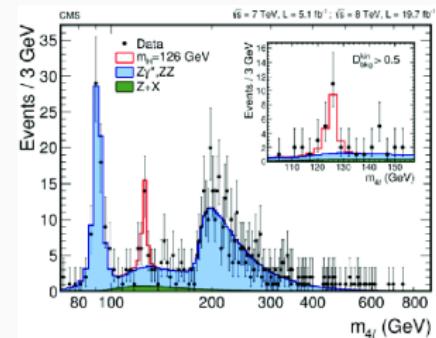
$$\mathcal{L} = i(L)^\dagger \bar{\sigma}^\mu D_\mu L - \frac{1}{4} W_{\mu\nu}^i W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + (e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda (\Phi^\dagger \Phi)^2$$

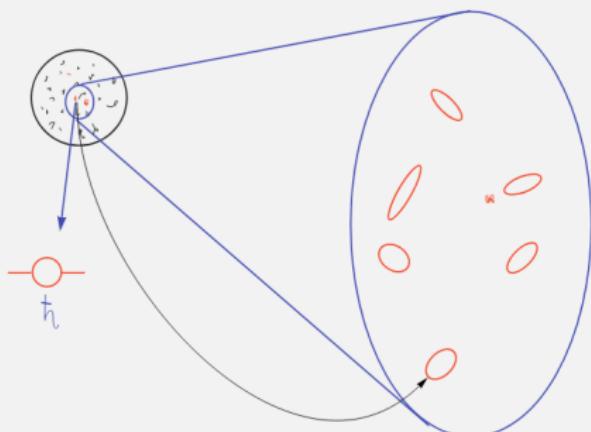
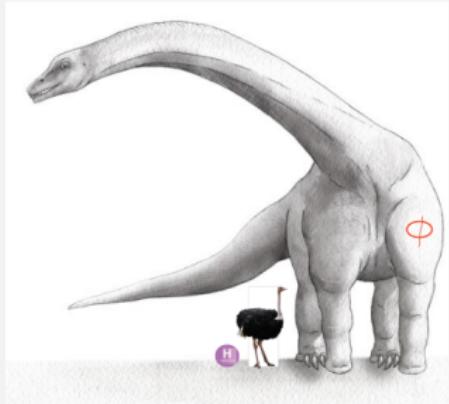
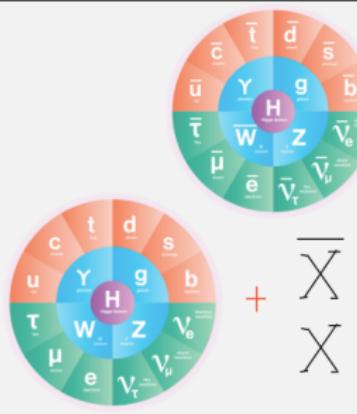
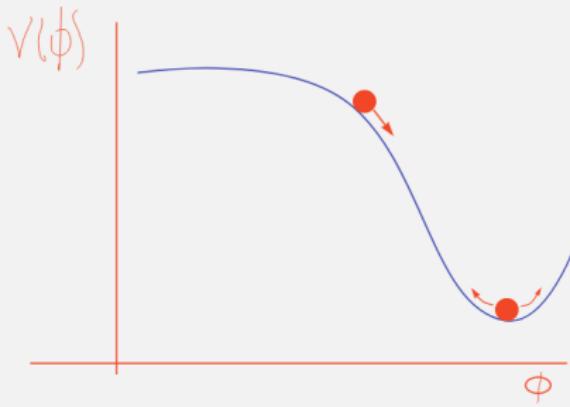
$$\Phi \rightarrow \Phi' = \exp \left[i \frac{\tau^i}{2} \theta_i(x) \right] \Phi = \frac{1}{\sqrt{2}} [H(x) + v]$$

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

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

Acceptance





en.wikipedia.org

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 ...

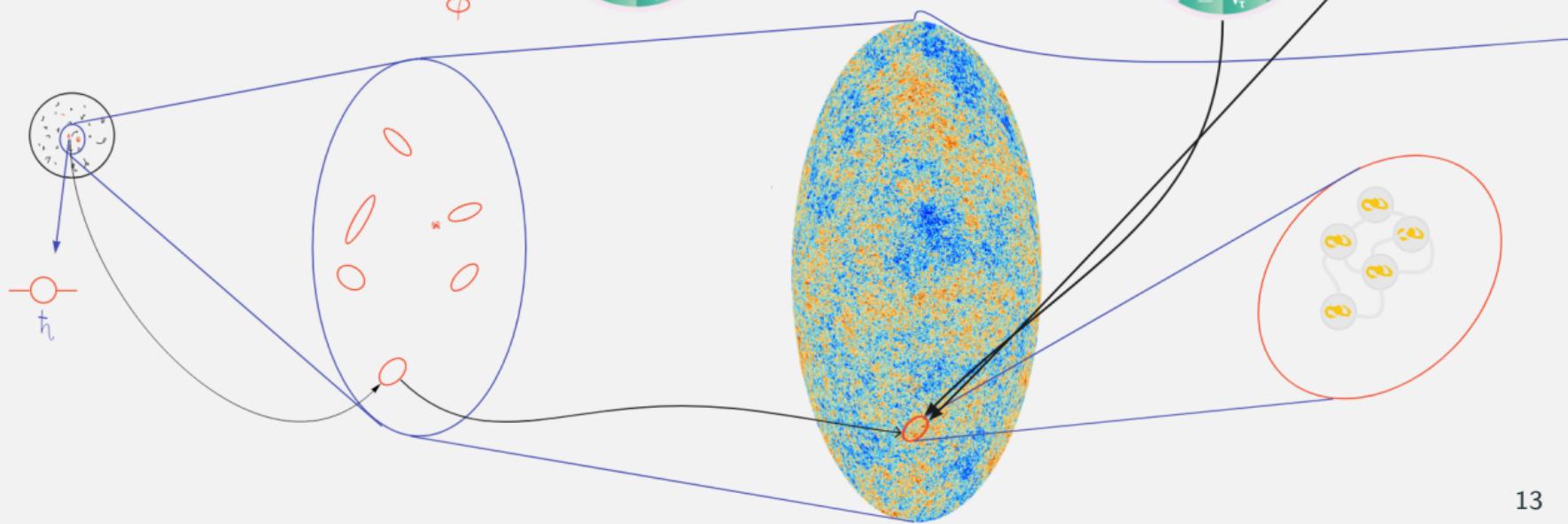
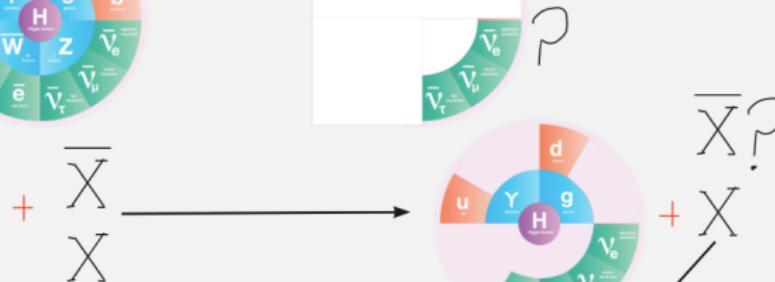
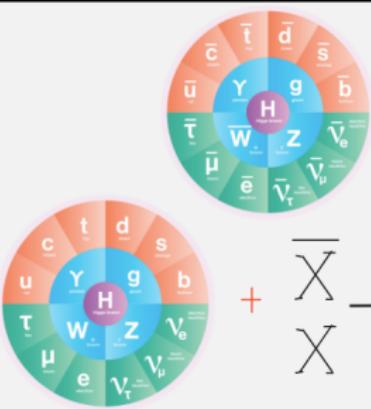
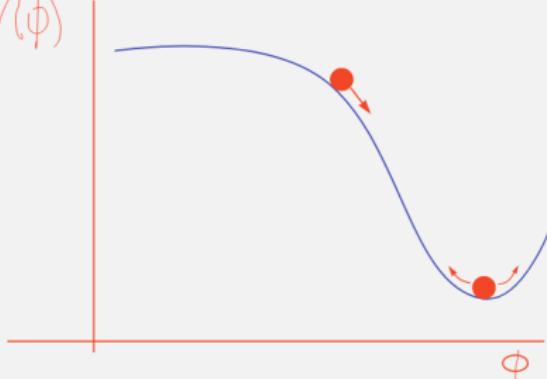


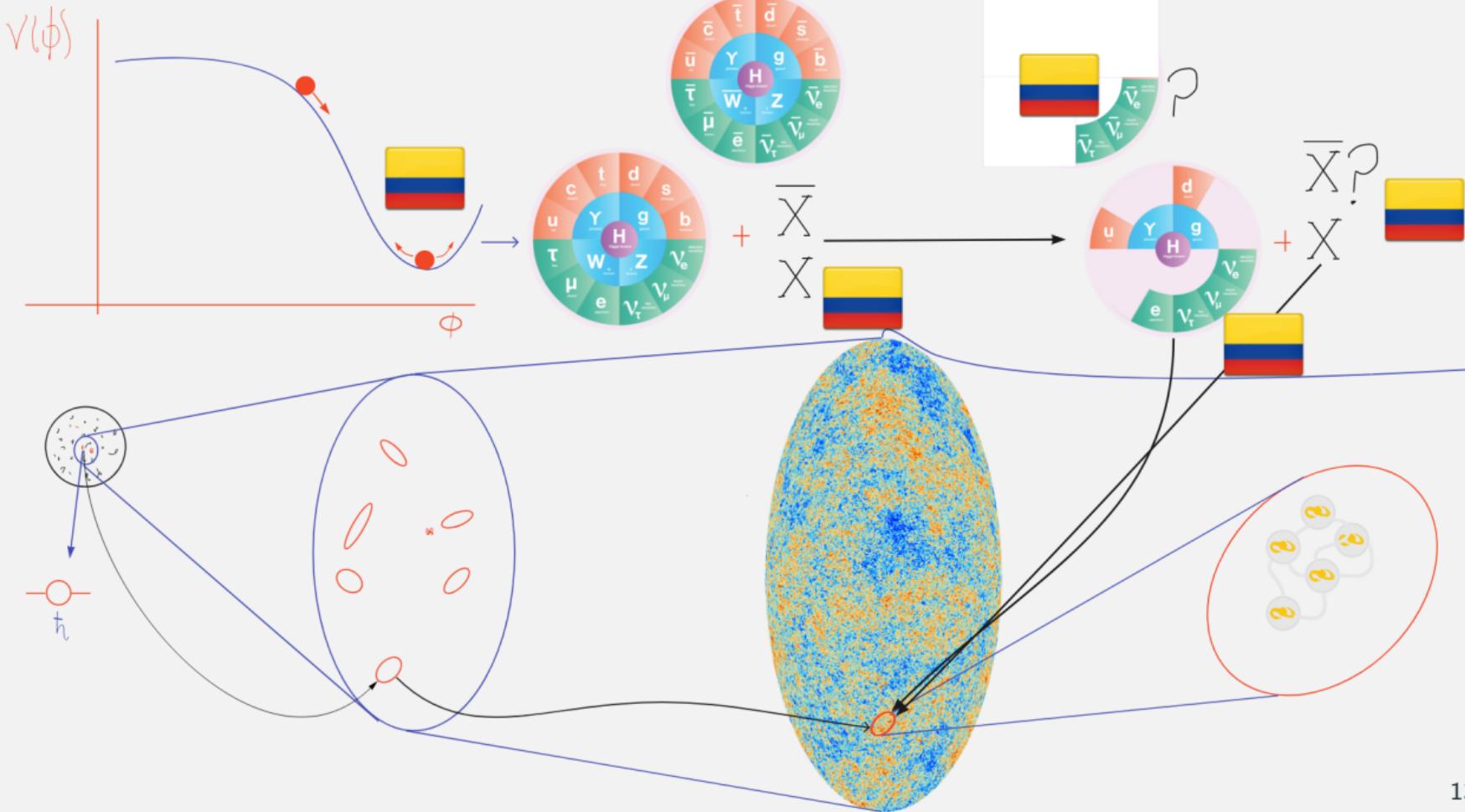
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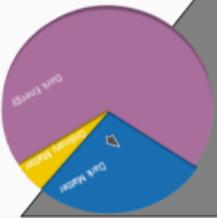
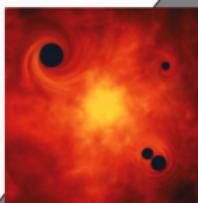
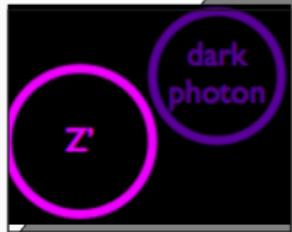
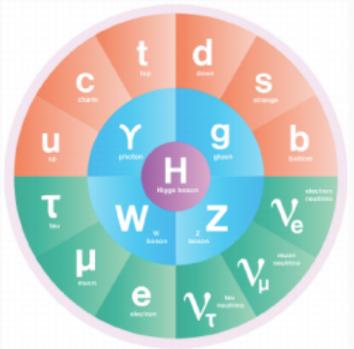
Fritz Zwicky - Wikipedia

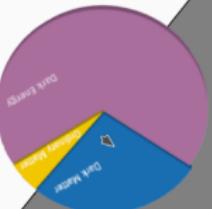
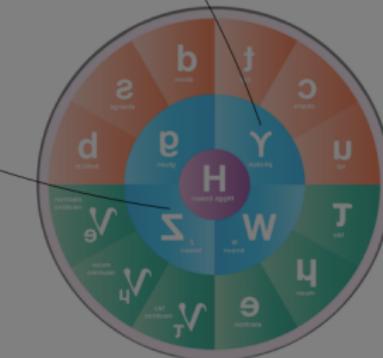
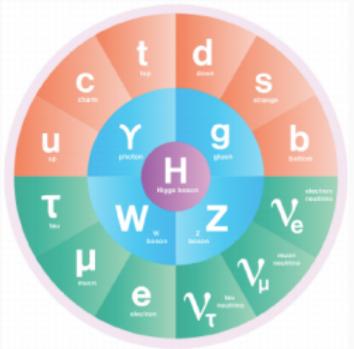
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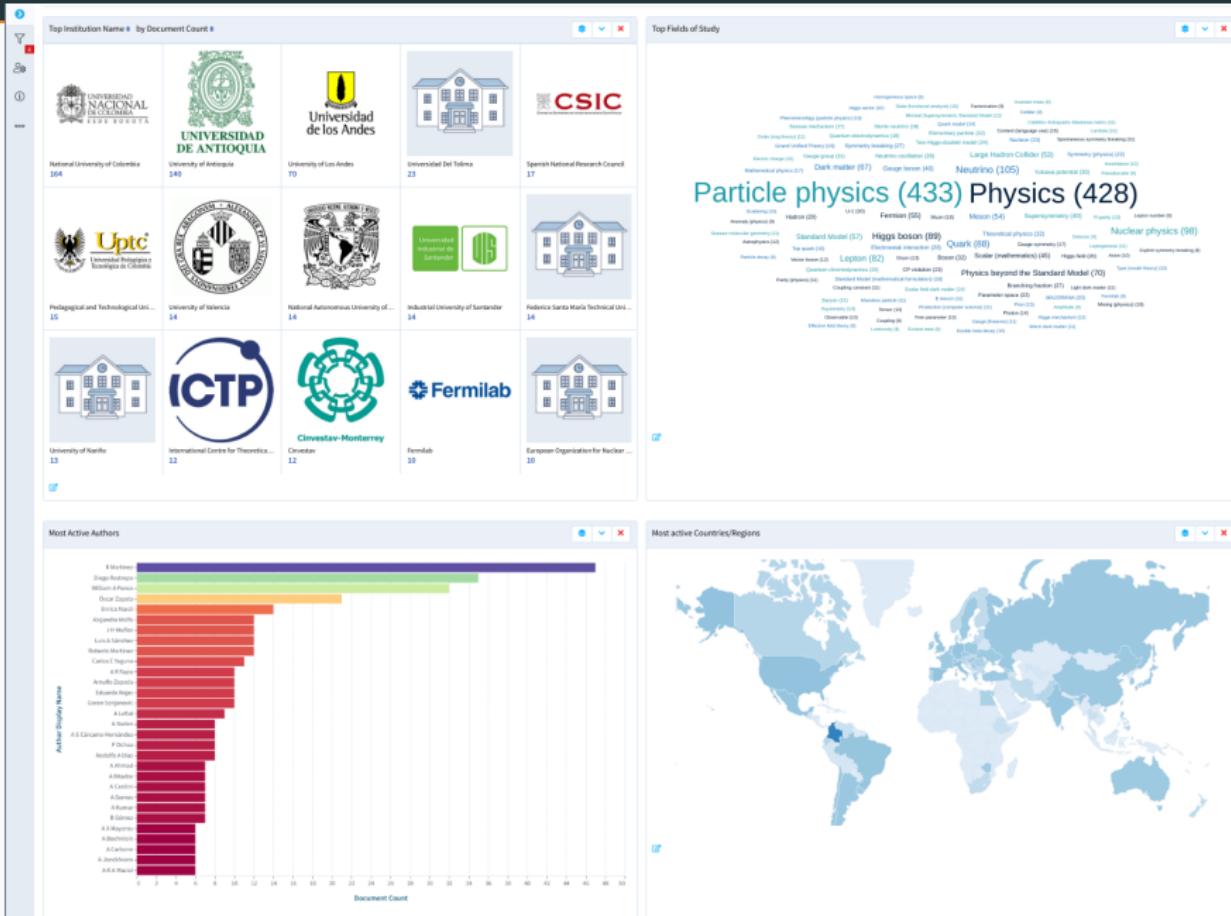
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arXiv:2104.06852v1 [hep-ex] 14 Apr 2021

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

En este trabajo se implementó una herramienta virtual, ie., un foro de discusión diseñado para el curso de Fluidos y Termodinámica de la Pontificia Universidad Javeriana. El propósito del foro es fomentar el trabajo en equipo y el aprendizaje en grupos colaborativos, así como también, contrarrestar la llamada curva del olvido. Al comienzo de esta experiencia, se evidencia una inercia por parte de los estudiantes, sin embargo durante el desarrollo de la misma, los estudiantes se dieron cuenta de la efectividad de la ...

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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.

