HEP computer tools

from SARAH and beyond

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XXIX CONGRESO NACIONAL DE FÍSICA
vigesimonoveno

Least Action

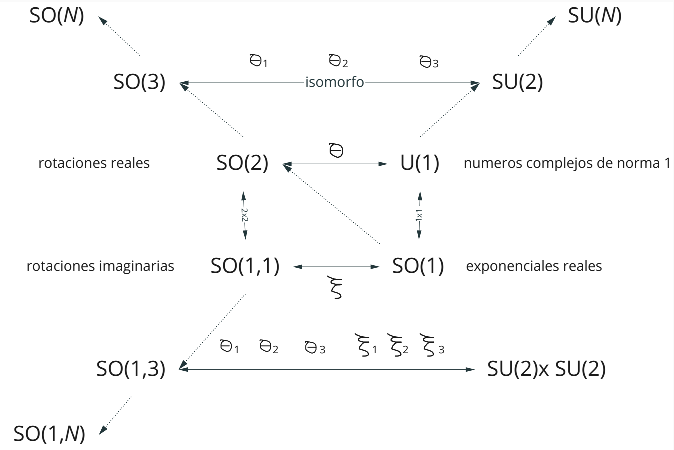
SO(3) **scalar product**

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

SO(3) **scalar product**

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

Lie groups



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

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

Consider the 1×1

$$K = -i \,, \tag{2}$$

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

$$\lambda(\xi) = \mathrm{e}^{\xi} \,, \tag{3}$$

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

$$x \to x' = \mathrm{e}^{\xi}\, x \,, \tag{4}$$

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

$$x \cdot y \to x' \cdot y' \equiv \frac{x'}{y'} = \frac{\mathrm{e}^{\xi}\, x}{\mathrm{e}^{\xi}\, y} = \frac{x}{y} = x \cdot y \,. \tag{5}$$

SO(1, 1)

Queremos obtener una representación 2×2 del álgebra

$$K = \begin{pmatrix} 0 & -i \\ -i & 0 \end{pmatrix} \to K^2 = -\mathbf{1}\,, \tag{6}$$

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

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

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

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

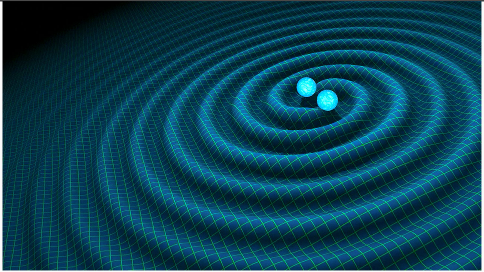
$$x'^\mu = \Lambda^\mu{}_\nu x^\nu\,, \qquad \mu = 0, 1\,.$$

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

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

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

Inestability of binary particle systems

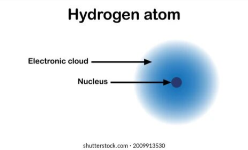


Gravitational wave discovery by LIGO

credits: science.org

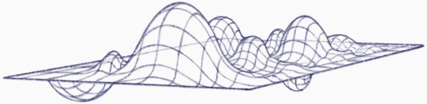
Noether's paradigm $\rightarrow$ Lagrangian formulation of classical field theory

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

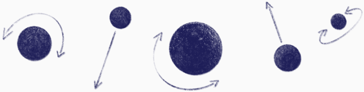


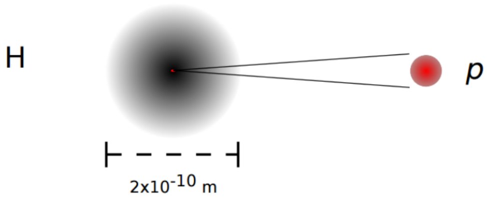
What is a ~~particle~~ *wavicle*? `https://www.quantamagazine.org/what-is-a-particle-20201112/`

Is a "Quantum Excitation of a Field"



Is a "Irreducible Representation of a Group"



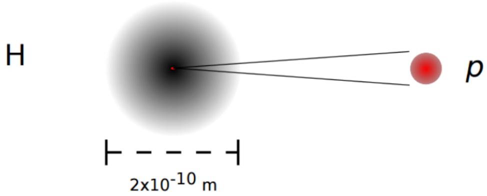

H
p
2x10-10 m

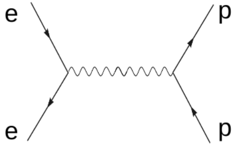
Interacción → Fuerza = $\Delta \mathbf{p}/\Delta t$

Introducción

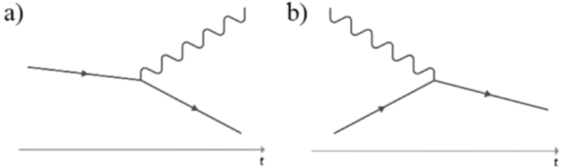
Campos de materia

Campos de radiación





doi:10.1088/1742-6596/1287/1/012045



Emisión absorción

Interacción → Fuerza = $\Delta \mathbf{p}/\Delta t$

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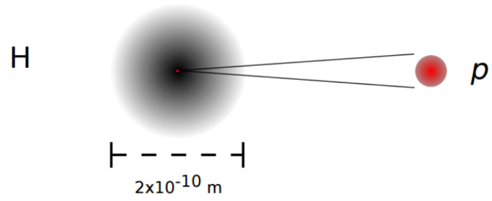

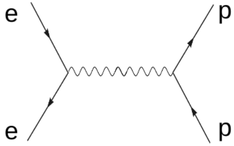

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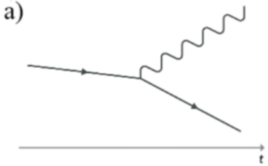
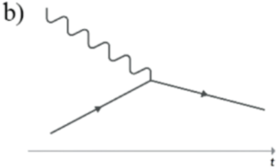


Emisión

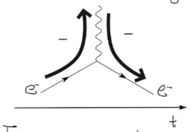


absorción

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

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

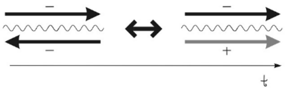
Single charge

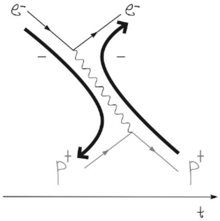


Fuerza $\frac{\Delta \vec{p}}{\Delta t} \neq 0$

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

fotón neutro





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

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

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

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

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

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

the tranformation properties for a $\partial_{\mu} = \partial/\partial x^{\mu}$, are

$$\partial'_{\mu} = \partial_{\nu} \left(\Lambda^{-1}\right)^{\nu}{}_{\mu}\,. \tag{11}$$

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

$$\partial_{\mu} A^{\mu} \to \partial'_{\mu} A'^{\mu} = \partial_{\mu} A^{\mu}\,. \tag{12}$$

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

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

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

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

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

Photon: $\hat{\boldsymbol{p}} \oplus \mathrm{SO}(1,3) = i\partial^\mu \oplus \mathrm{SO}(1,3) \to i\,D^\mu \oplus \mathrm{SO}(1,3)$

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Name	Symbol	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	$(\xi_\alpha)^\dagger = \xi^\dagger_{\dot\alpha}$	$\xi^\dagger_{\dot\beta}\left[S^\dagger\right]^{\dot\beta}{}_{\dot\alpha}$	$\xi^\dagger_{\dot\alpha} e^{-i\theta}$
e_R: electron right	$(\eta^\alpha)^\dagger = \eta^{\dagger\,\dot\alpha}$	$\left[\left(S^{-1}\right)^\dagger\right]^{\dot\alpha}{}_{\dot\beta}\eta^{\dagger\,\dot\beta}$	$e^{i\theta}\eta^{\dagger\,\dot\alpha}$
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Table 3: electron left: SL(2, C) $\times$ $U(1)$ inferior and positron left: SL(2, C) $\times$ $U(1)$ superior

Scalar products

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

$$\sigma^0 = \mathbb{1}\,, \qquad \overline{\sigma}^\mu = (\sigma^0, -\boldsymbol{\sigma}), \qquad \sigma^\mu = (\sigma^0, \boldsymbol{\sigma}).$$

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

$$\xi_\alpha \to \xi'_\alpha = e^{i\theta(x)}\xi_\alpha \qquad \eta^\alpha \to \eta'^\alpha = e^{-i\theta(x)}\eta^\alpha$$

$$D_\mu\xi_\alpha \to (D_\mu\xi_\alpha)' = e^{i\theta(x)} D_\mu\xi_\alpha \qquad D_\mu\eta^\alpha \to (D_\mu\eta^\alpha)' = e^{-i\theta(x)} D_\mu\eta^\alpha$$

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

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$$\mathcal{L} = i\overline{\psi}\gamma^\mu D_\mu\psi - m\overline{\psi}\psi - \frac{1}{4}F^{\mu\nu}F_{\mu\nu}\,.$$

Dirac spinor

$$\psi = \begin{pmatrix} e_L \\ e_R \end{pmatrix}$$

$$\gamma^\mu = \begin{pmatrix} 0 & \sigma^\mu \\ \overline{\sigma}^\mu & 0 \end{pmatrix}$$

$$\overline{\psi} = \psi^\dagger\gamma^0\,.$$

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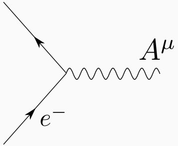
Dirac spinor



$-ie\gamma^\mu$

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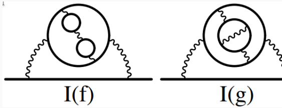
Dirac spinor

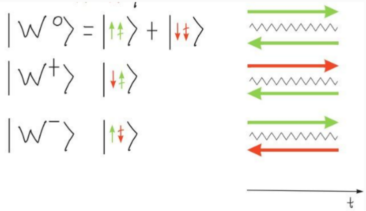
non-bare



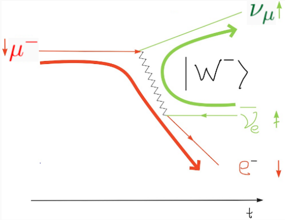
Not mass, not charge

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

Denial



$$\mathcal{L} = i\,(L)^\dagger\,\overline{\sigma}^\mu D_\mu L - \tfrac{1}{4}W^i_{\mu\nu}W_i^{\mu\nu}$$

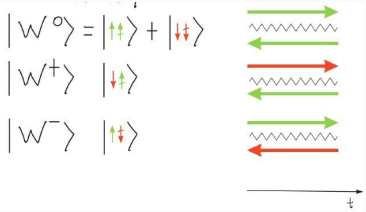


$SU(2)_L \times U(1)_Y \rightarrow D_\mu = \mathbf{1}\partial_\mu - i g_2 \frac{\tau_i}{2} W^i_\mu - i g_1 B_\mu$: 17 years later... (stages of grief $\rightarrow$ 1967)

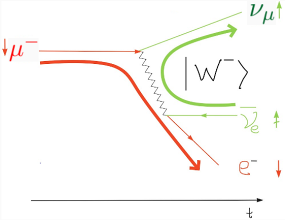
Not mass, hypercharge,

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

Denial



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

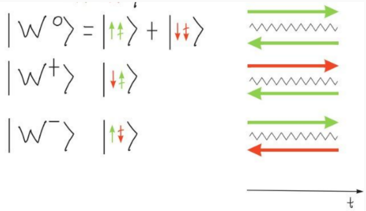


$SU(2)_L \times U(1)_Y \rightarrow D_\mu = 1\partial_\mu - ig_2 \frac{\tau_i}{2} W^i_\mu - ig_1 B_\mu$: 17 years later... (stages of grief → 1967)

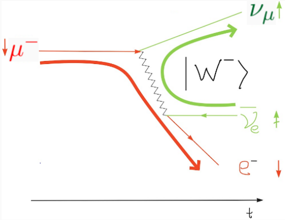
Not mass, hypercharge, not Dirac

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

Denial



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

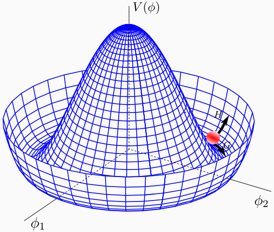


$SU(2)_L \times U(1)_Y \to D_\mu = 1\partial_\mu - ig_2 \frac{\tau_i}{2} W^i_\mu - ig_1 B_\mu$: 17 years later... (stages of grief → 1967)

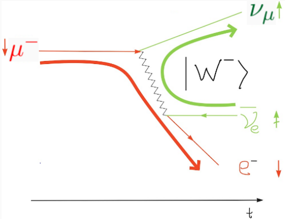
Higgs mechanism: tachyonic mass $\mu^2 < 0$, and condensate

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**	$1/2$

Contempt



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



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

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Contempt

$$\begin{pmatrix} W^3_\mu \\ B_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta_W & \sin\theta_W \\ -\sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} Z_\mu \\ A_\mu \end{pmatrix},$$

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

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

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

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

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

Z and W phenomenology and discovery

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

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

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

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

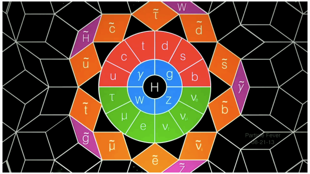
$$-\frac{1}{2}m_H^2H^2\left(1+\frac{H}{v}+\frac{H^2}{4v^2}\right) + \left(m_W^2 W^{\mu-}W^+_\mu + \frac{1}{2}m_Z^2 Z^\mu Z_\mu\right)\left(1+2\frac{H}{v}+\frac{H^2}{v^2}\right) + \frac{m_e}{v}\overline{\psi}\psi H$$

$SU(2)_L \times U(1)_Y \rightarrow D_\mu = 1\partial_\mu - ig_2\frac{\tau_i}{2}W^i_\mu - ig_1 B_\mu$: 32 years later... (stages of grief → 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**	$1/2$

Depression



credit: quantumdiaries.org

$$\mathcal{L} = i(L)^\dagger \overline{\sigma}^\mu D_\mu L - \frac{1}{4}W^i_{\mu\nu}W^{\mu\nu}_i - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + h(e_R)^\dagger \Phi^\dagger L - (D^\mu\Phi)^\dagger D_\mu\Phi - \mu^2\Phi^\dagger\Phi - \lambda(\Phi^\dagger\Phi)$$

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

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

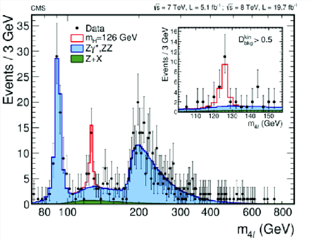
$$-\frac{1}{2}m_H^2H^2\left(1+\frac{H}{v}+\frac{H^2}{4v^2}\right) + \left(m_W^2W^{\mu-}W^+_\mu + \frac{1}{2}m_Z^2Z^\mu Z_\mu\right)\left(1+2\frac{H}{v}+\frac{H^2}{v^2}\right) + \frac{m_e}{v}\overline{\psi}\psi H$$

$SU(2)_L \times U(1)_Y \to D_\mu = 1\partial_\mu - i g_2 \frac{\tau_i}{2} W^i_\mu - i g_1 B_\mu$: 62 years later... (stages of grief $\to$ 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**	$1/2$

Acceptance

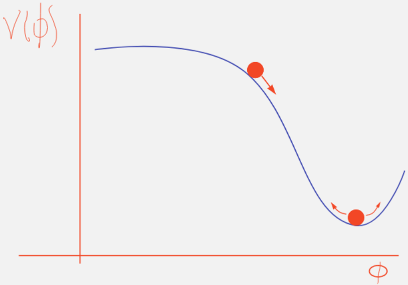


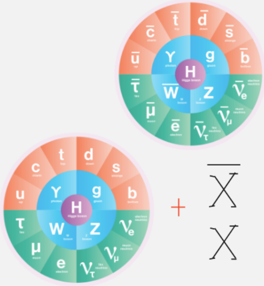
$$\mathcal{L} = i(L)^\dagger \overline{\sigma}^\mu D_\mu L - \frac{1}{4} W^i_{\mu\nu} W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} - i(e_R)^\dagger \sigma^\mu D_\mu e_R + h(e_R)^\dagger \Phi^\dagger L - (D^\mu \Phi)^\dagger D_\mu \Phi - \mu^2 \Phi^\dagger \Phi - \lambda\left(\Phi^\dagger \Phi\right)$$

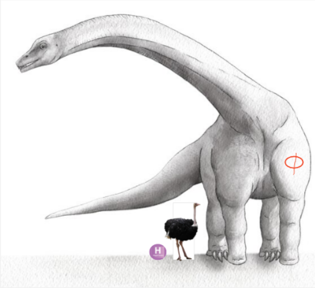
$$\Phi \to \Phi' = \exp\left[i\frac{\tau^i}{2}\theta_i(x)\right]\Phi = \frac{1}{\sqrt{2}}[H(x)+v]$$

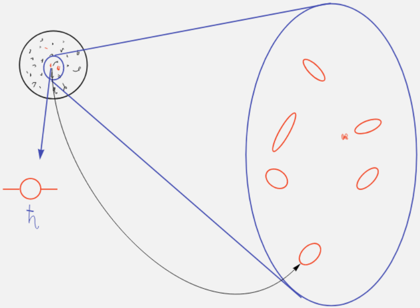
$$\mathcal{L} = i\overline{\psi}\gamma^\mu \partial \psi - m_e \overline{\psi}\psi - i(\nu_L)^\dagger \overline{\sigma}^\mu \partial_\mu \nu_L + \frac{1}{2}\partial^\mu H \partial_\mu H + \frac{e}{\cos\theta_W \sin\theta_W} \overline{\nu_L}\nu_L Z_\mu + \cdots$$

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









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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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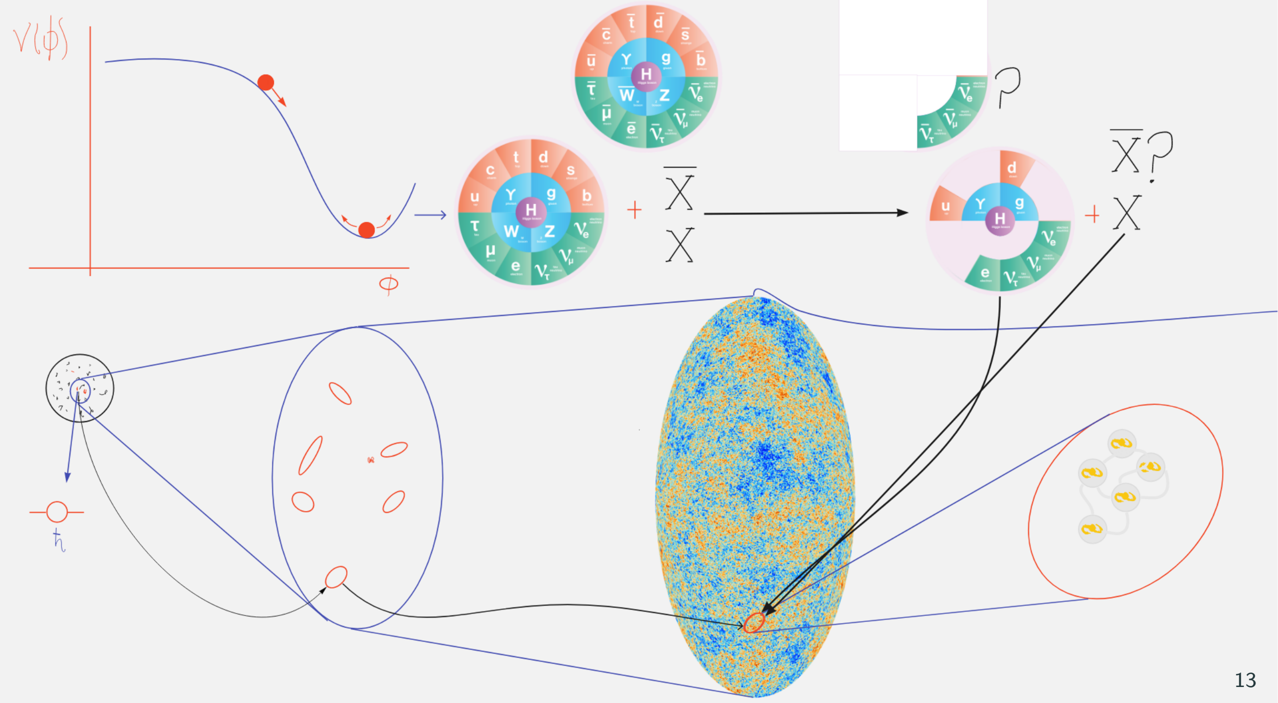
Fritz Zwicky - Wikipedia

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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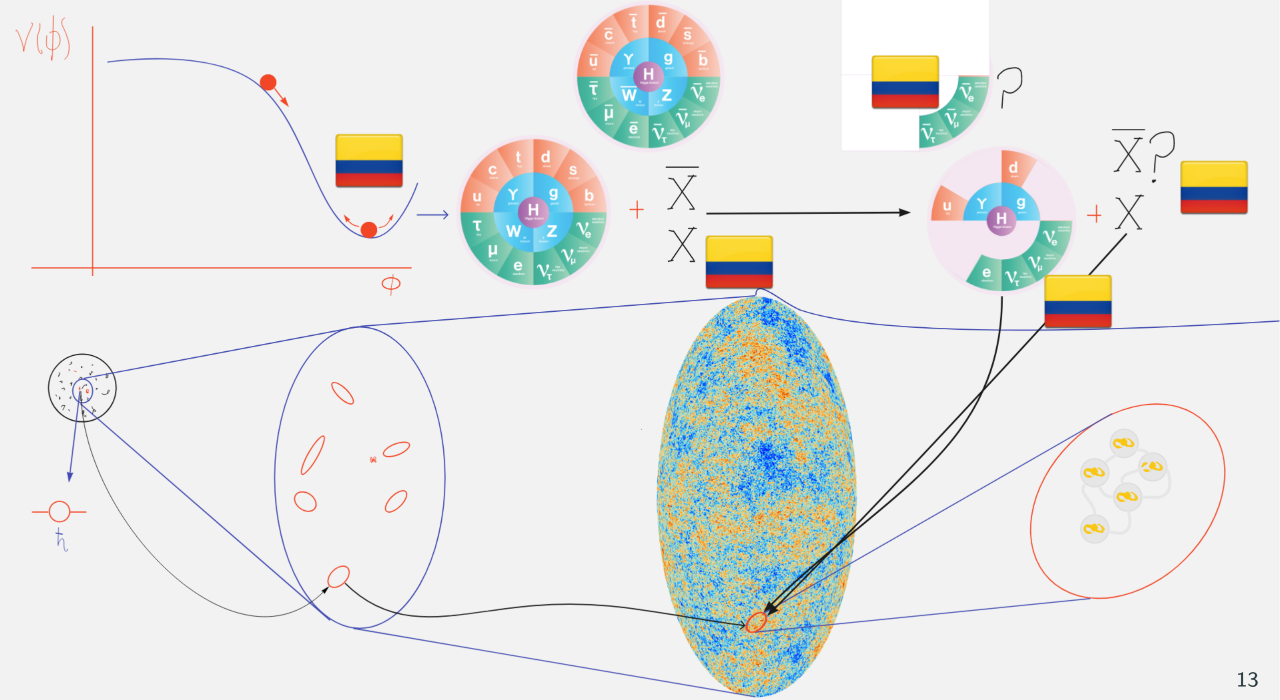
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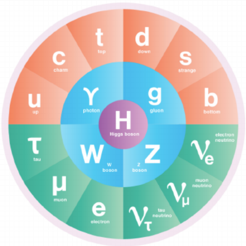
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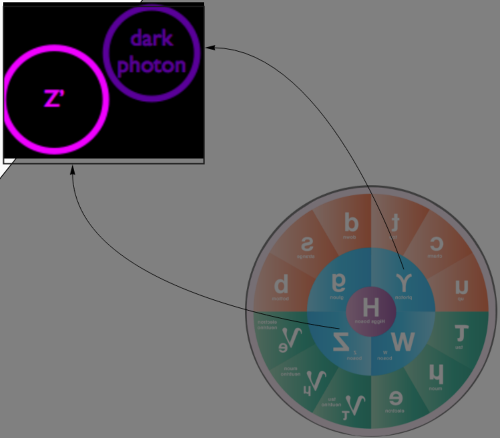
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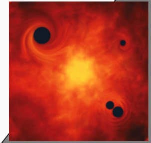

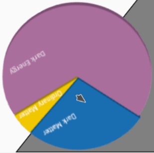
Dark Energy
Ordinary Matter
Dark Matter


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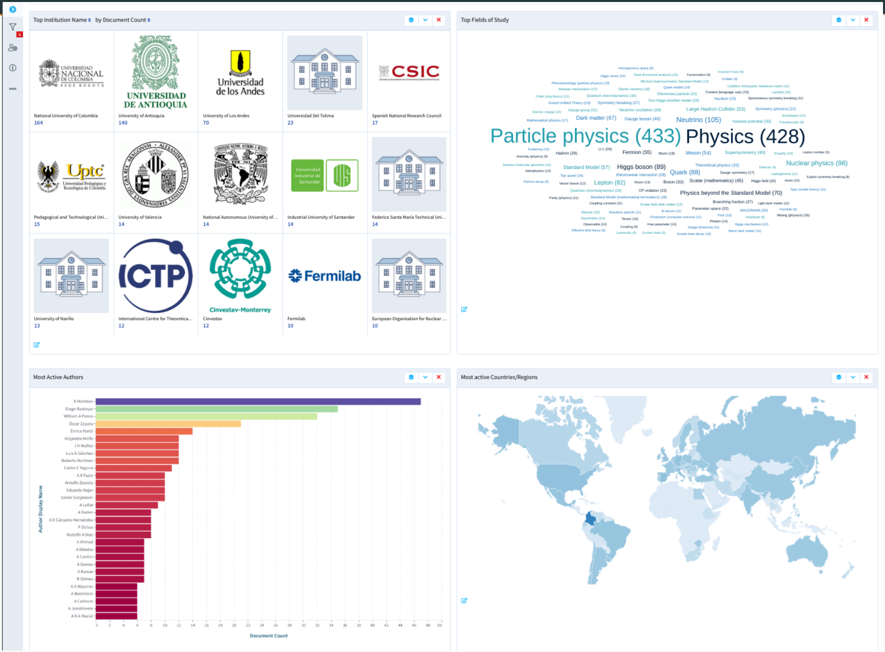
Ordinary Matter
Dark Matter

Particle physics without hep-ex in Colombia in lens.org



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Latin American Strategy for Research Infrastructures for High Energy, Cosmology, Astroparticle Physics LASF4RI for HECAP

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

LATIN AMERICAN HECAP PHYSICS BRIEFING BOOK

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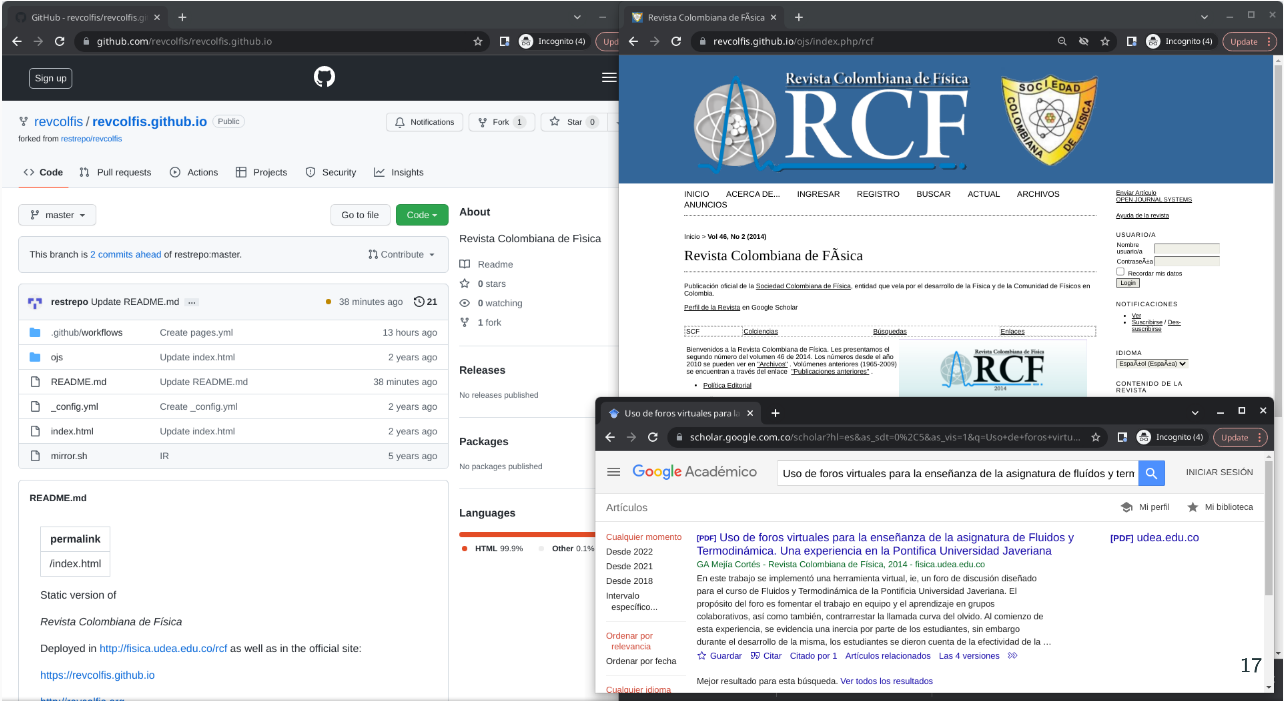
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Go to file
Code
This branch is 2 commits ahead of restrepo:master.
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21
.github/workflows Create pages.yml 13 hours ago
ojs Update index.html 2 years ago
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Enlaces
Bienvenidos a la Revista Colombiana de Física. Les presentamos el segundo número del volumen 46 de 2014. Los números desde el año 2010 se pueden ver en "Archivos". Volúmenes anteriores (1965-2009) se encuentran a través del enlace "Publicaciones anteriores".
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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.