ESTRUCTURA DE LA MATERIA 4

CURSO DE VERANO 2021

CLASE 16

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CLASE 16: Generación de masas en la teoría electrodébil.

Temas: acoplamientos y masas para campos de gauge, masas para fermiones, fenomen.

campos de gauge:

$$W^a_\mu \longrightarrow W^a_\mu + \frac{1}{g}\partial_\mu \alpha^a - f_{abc}\alpha^b W^c_\mu$$

$SU(2)_L$ $\quad \Psi^e_L = \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L$ $\quad \Psi^e_L \longrightarrow \Psi'^e_L = e^{i\alpha_i(x)T_i}\Psi^e_L$ $\quad T_i \equiv \frac{\sigma_i}{2}$

$U(1)$ $\quad e_L, e_R, \nu_L$ $\quad e \longrightarrow e' = e^{i\beta(x)Y} e$

$$\begin{cases} \Psi^e_L \longrightarrow \Psi'^e_L = e^{i\alpha_i(x)T_i + i\beta(x)Y}\Psi^e_L \\ e_R \longrightarrow e'_R = e^{i\beta(x)Y} e_R \end{cases}$$

$$\Psi^e_L = \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L \quad T = \frac{1}{2} \quad Y = -1$$

$$e_R \quad T = 0 \quad Y = -2$$

$$Q = T^3 + \frac{Y}{2}$$

$$J^i_\mu \equiv \overline{\Psi}_L \gamma_\mu T^i \Psi_L \sim g\, J^i_\mu W^\mu_i$$

$$J^Y_\mu \equiv \bar{e}\,\gamma_\mu Y e \sim \frac{g'}{2} J^Y_\mu B^\mu$$

p. ej. $e_R \quad Q = 0 + \frac{-2}{2} = -1$

$e_L \quad Q = \frac{-1}{2} + \frac{-1}{2} = -1$

$\nu_e \quad Q = \frac{1}{2} + \frac{-1}{2} = 0$

$$J^{em}_\mu = J^3_\mu + \frac{1}{2}J^Y_\mu$$

$$J^3_\mu = (\overline{\nu_e}, e_L)\,\frac{\gamma_\mu}{2}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}\begin{pmatrix} \nu_e \\ e_L \end{pmatrix} = \frac{1}{2}\overline{\nu_e}\gamma_\mu\nu_e - \frac{1}{2}\overline{e_L}\gamma_\mu e_L$$

$$\frac{1}{2}J^Y_\mu = -\frac{2}{2}\overline{e_R}\gamma_\mu e_R - \frac{1}{2}\overline{e_L}\gamma_\mu e_L - \frac{1}{2}\overline{\nu_e}\gamma_\mu\nu_e$$

$$J^{em}_\mu = -\overline{e_R}\gamma_\mu e_R - \overline{e_L}\gamma_\mu e_L$$

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campos de gauge:

$$\sim g\, J^i_\mu W^\mu_i + \frac{g'}{2} J^Y_\mu B^\mu = \underbrace{g\, J^1_\mu W^\mu_1 + g\, J^2_\mu W^\mu_2}_{W^+_\mu,\, W^-_\mu} + \underbrace{g\, J^3_\mu W^\mu_3 + \frac{g'}{2} J^Y_\mu B^\mu}_{A_\mu,\, Z_\mu}$$

$$\begin{cases} A_\mu \equiv B_\mu \cos\theta_W + W^3_\mu \sin\theta_W \\ Z^0_\mu \equiv -\, B_\mu \sin\theta_W + W^3_\mu \cos\theta_W \end{cases} \qquad \begin{cases} W^3_\mu \equiv A_\mu \sin\theta_W + Z_\mu \cos\theta_W \\ B_\mu \equiv A_\mu \cos\theta_W - Z_\mu \sin\theta_W \end{cases}$$

$$g\, J^3_\mu W^\mu_3 + \frac{g'}{2} J^Y_\mu B^\mu = g\, J^3_\mu (A^\mu \sin\theta_W + Z^\mu \cos\theta_W) + \frac{g'}{2} J^Y_\mu (A^\mu \cos\theta_W - Z^\mu \sin\theta_W)$$

$$= A^\mu \underbrace{(g \sin\theta_W J^3_\mu + \frac{g'}{2} \cos\theta_W J^Y_\mu)}_{J^{em}_\mu = J^3_\mu + \frac{1}{2} J^Y_\mu} + Z^\mu (g \cos\theta_W J^3_\mu - \frac{g'}{2} \sin\theta_W J^Y_\mu)$$

$$g \sin\theta_W = g' \cos\theta_W = e$$

$$= e\, A^\mu J^{em}_\mu + \frac{e}{\sin\theta_W \cos\theta_W} Z^\mu (\cos^2\theta_W J^3_\mu - \sin^2\theta_W J^Y_\mu)$$

$$(g, g') \leftrightarrow (e, \sin\theta_W)$$

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campos de gauge:

$$\mathscr{L}_1 = \overline{\Psi}_L \gamma^\mu [\underbrace{i\partial_\mu + gT^i W_\mu^i + \frac{g'}{2} Y B_\mu}_{iD_\mu}] \Psi_L + \overline{e_{R_L}} \gamma^\mu [\underbrace{i\partial_\mu + gT^i W_\mu^i + \frac{g'}{2} Y B_\mu}_{iD_\mu}] e_R \quad \mathscr{L}_2 = -\frac{1}{4} W^i_{\mu\nu} W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$$

$$\mathscr{L}_3 = (D_\mu \Phi)^\dagger (D^\mu \Phi) - V(\Phi) = (\partial_\mu - igT^i W_\mu^i - i\frac{g'}{2} B_\mu)^\dagger \Phi^\dagger (\partial_\mu - igT^i W_\mu^i - i\frac{g'}{2} B_\mu) \Phi - V(\Phi) \qquad (Y = 1)$$

$$\Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix} e^{iT^i \theta_i(x)} \qquad \left| (-igT^i W_\mu^i - i\frac{g'}{2} B_\mu) \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix} \right|^2 = \frac{1}{2} v^2 \frac{1}{4} \left| (g\sigma^i W_\mu^i + g' B_\mu) \begin{pmatrix} 0 \\ 1 \end{pmatrix} \right|^2$$

$$= \frac{v^2}{8} \left| \begin{pmatrix} gW_\mu^3 + g'B_\mu & g(W_\mu^1 - iW_\mu^2) \\ g(W_\mu^1 + iW_\mu^2) & -gW_\mu^3 + g'B_\mu \end{pmatrix} \begin{pmatrix} 0 \\ 1 \end{pmatrix} \right|^2 = \frac{v^2}{8} \left| \begin{pmatrix} g(W_\mu^1 - iW_\mu^2) \\ -gW_\mu^3 + g'B_\mu \end{pmatrix} \right|^2$$

$$= \frac{v^2 g^2}{8} [(W_\mu^1)^2 + (W_\mu^2)^2] + \frac{v^2}{8} [(-gW_\mu^3 + g'B_\mu)^2] = M_W^2 W_\mu^+ W^{-\mu} + \frac{1}{2} M_Z^2 Z_\mu Z^\mu + \frac{1}{2} M_A^2 A_\mu A^\mu$$

$$M_W = \frac{1}{2} vg \qquad M_Z = \frac{1}{2} v\sqrt{g^2 + g'^2} \qquad M_A = 0$$

$$g \sin\theta_W = g' \cos\theta_W = e \qquad M_Z = \frac{M_W}{\cos\theta_W} \qquad M_Z = 91.2\, GeV \qquad M_W = 79.69\, GeV \qquad v \sim 246\, GeV \qquad \theta_W \sim 30^o$$

$$\begin{cases} A_\mu \equiv B_\mu \cos\theta_W + W_\mu^3 \sin\theta_W \\ Z_\mu^0 \equiv -B_\mu \sin\theta_W + W_\mu^3 \cos\theta_W \end{cases}$$

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campos fermiónicos:

$$\mathscr{L}_4 = -G_e\left[(\overline{\nu}_e, \overline{e})_L \,\Phi\, e_R + \overline{e}_R\,\overline{\Phi}\begin{pmatrix}\nu_e\\ e\end{pmatrix}_L\right] \qquad \Phi = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v+h(x)\end{pmatrix}$$

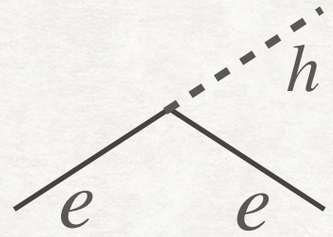
$$= -\underbrace{\frac{G_e}{\sqrt{2}}}\, v\,(\overline{e}_L e_R + \overline{e}_R e_L) - \frac{G_e}{\sqrt{2}}\, h\,(\overline{e}_L e_R + \overline{e}_R e_L)$$

m_e

$$m_e = \frac{G_e\, v}{\sqrt{2}}$$

$$m_e = 0.511\, MeV$$
$$v \sim 246\, GeV$$

$$G_e \sim 10^{-6}$$

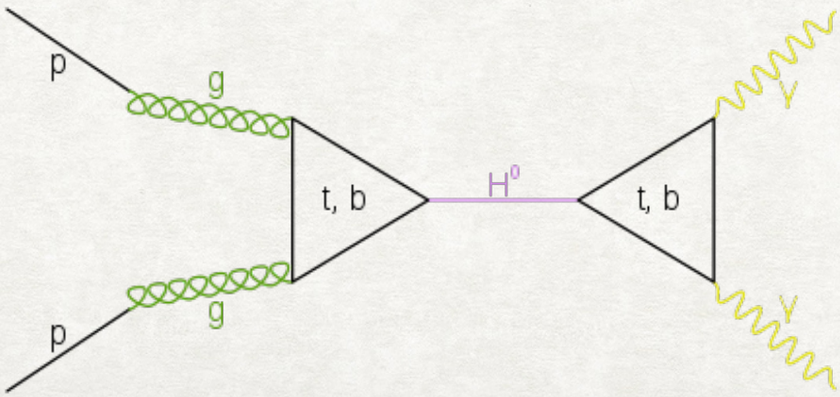


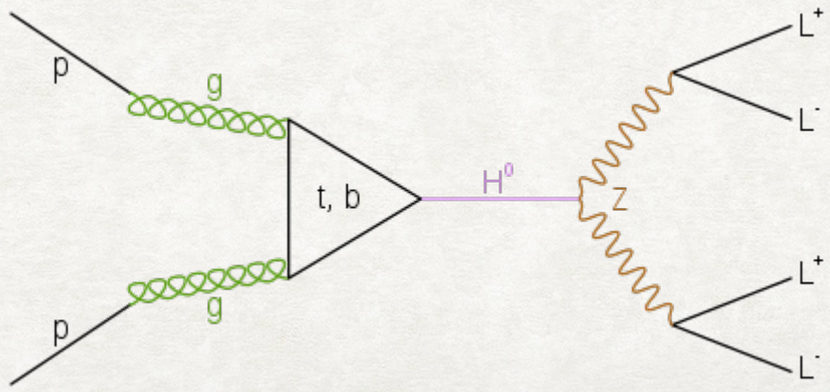
$$m_t = 174\, GeV$$

$$G_t \sim 10^{-3}$$

$$m_h^2 = 2\lambda v^2$$

$$m_h \sim 125\, GeV$$





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campos fermiónicos:

$$\mathscr{L}_4 = -G_e\left[(\overline{\nu}_e,\overline{e})_L\,\Phi\,e_R + \overline{e}_R\,\overline{\Phi}\begin{pmatrix}\nu_e\\ e\end{pmatrix}_L\right] \qquad \Phi = \frac{1}{\sqrt{2}}\begin{pmatrix}0\\ v+h(x)\end{pmatrix}$$

$$= -\underbrace{\frac{G_e}{\sqrt{2}}}\,v\,(\overline{e}_L e_R + \overline{e}_R e_L) - \frac{G_e}{\sqrt{2}}\,h\,(\overline{e}_L e_R + \overline{e}_R e_L) \qquad m_\nu = 0$$

m_e

$$\Phi = \frac{1}{\sqrt{2}}\begin{pmatrix}\phi^+\\ \phi^0\end{pmatrix}$$

$$\mathscr{L}_5 = -G_d\left[\left(\overline{u},\overline{d'}\right)_{\mathbb{L}}\mathbf{\Phi}\,\boldsymbol{d'_R} + \overline{\boldsymbol{d'}}_{\mathbb{R}}\overline{\mathbf{\Phi}}\begin{pmatrix}\boldsymbol{u}\\ \boldsymbol{d'}\end{pmatrix}_{\mathbb{L}}\right] - G_u\left[\left(\overline{u},\overline{d'}\right)_{\mathbb{L}}\tilde{\mathbf{\Phi}}\,\mathbb{u}_{\mathbb{R}} + \overline{\mathbb{u}}_{\mathbb{R}}\overline{\tilde{\mathbf{\Phi}}}\begin{pmatrix}\boldsymbol{u}\\ \boldsymbol{d'}\end{pmatrix}_{\mathbb{L}}\right] \qquad \tilde{\Phi} = \frac{1}{\sqrt{2}}\begin{pmatrix}-\overline{\phi^0}\\ \phi^-\end{pmatrix}$$

eligiendo convenientemente G_d, G_s, G_b se generan masas para d, s, b (y no para d', s', b')

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fenomenología:

1964

2001 LEP decomission

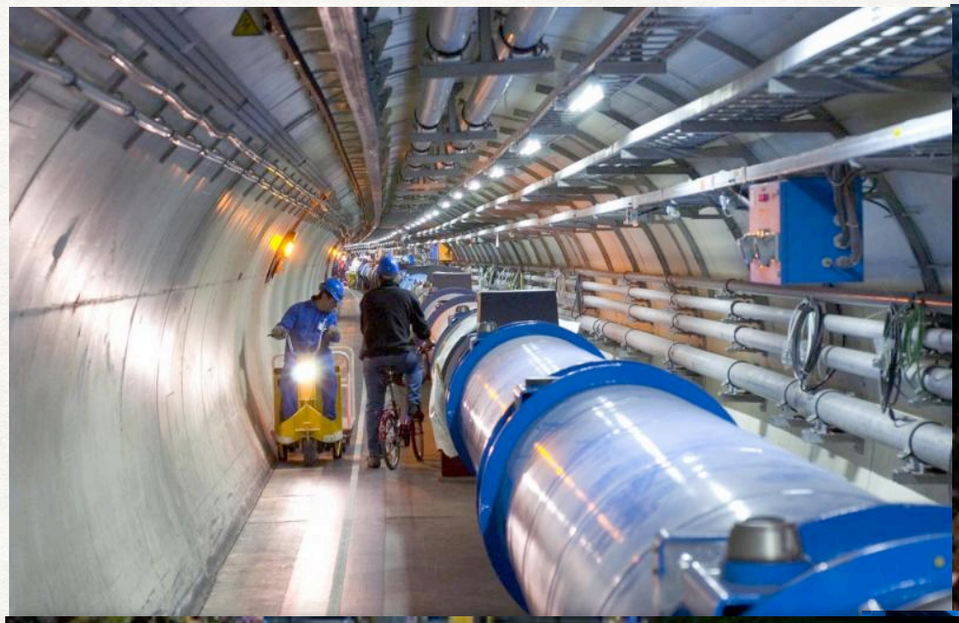
~200 GeV

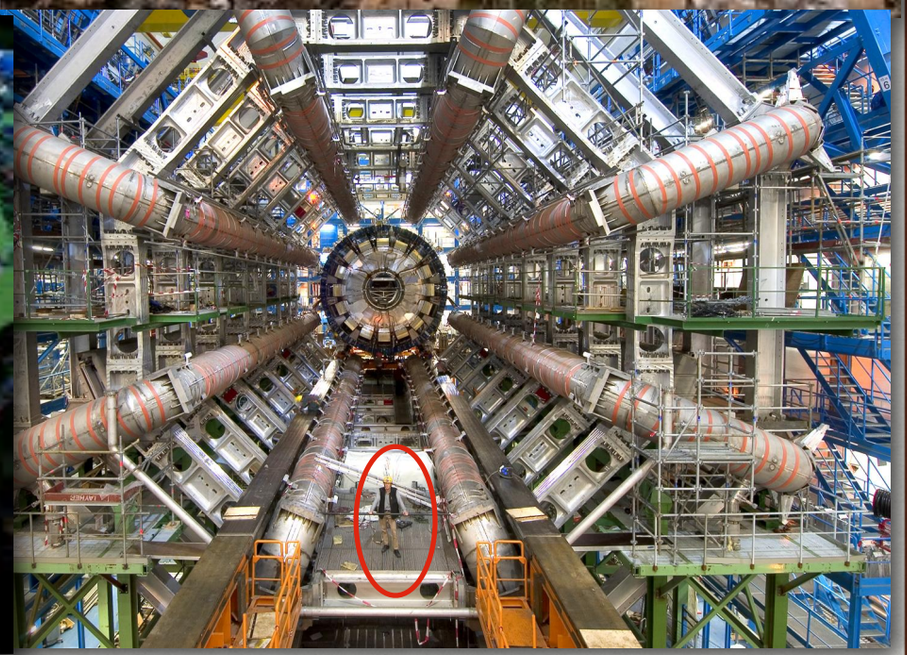
~14 TeV

2009 LHC startup

2012 discovery

2013 Nobel





2021 sin señales de nueva física

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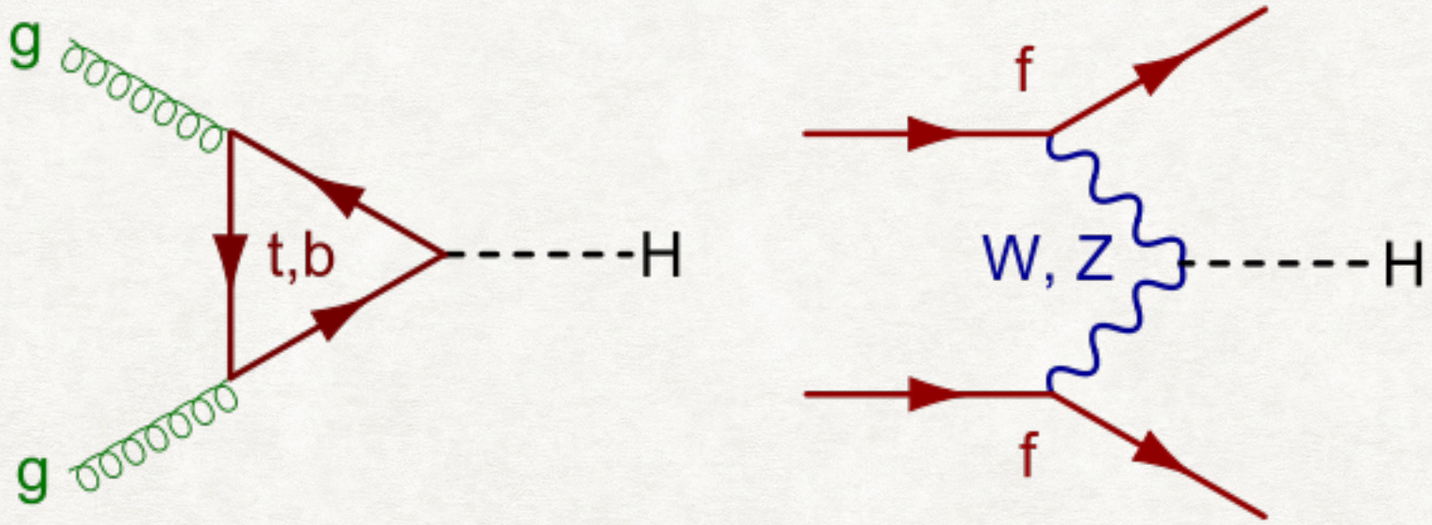
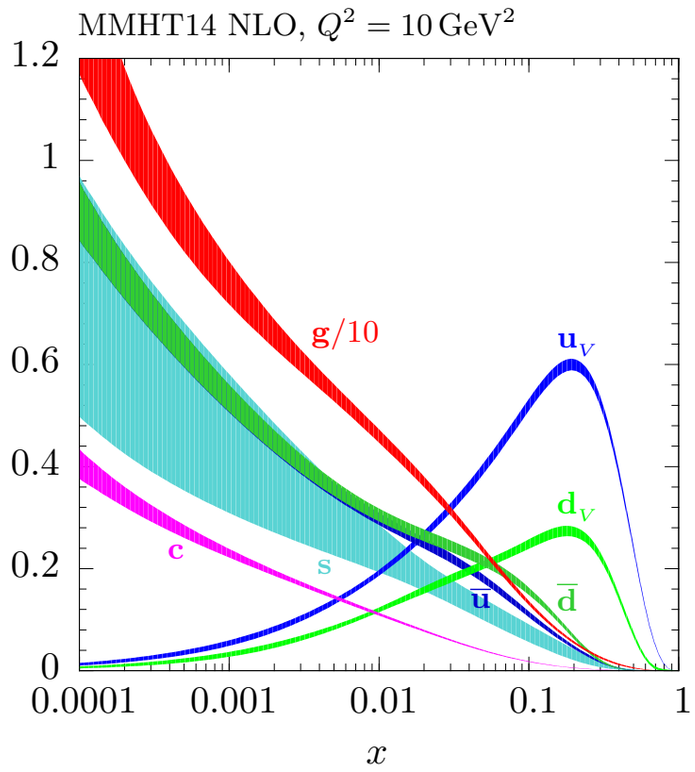
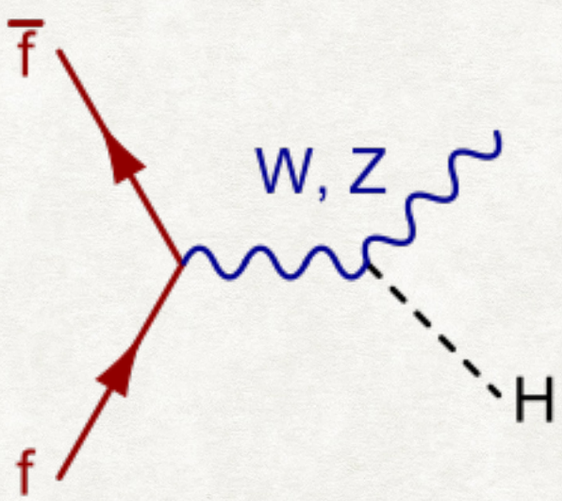
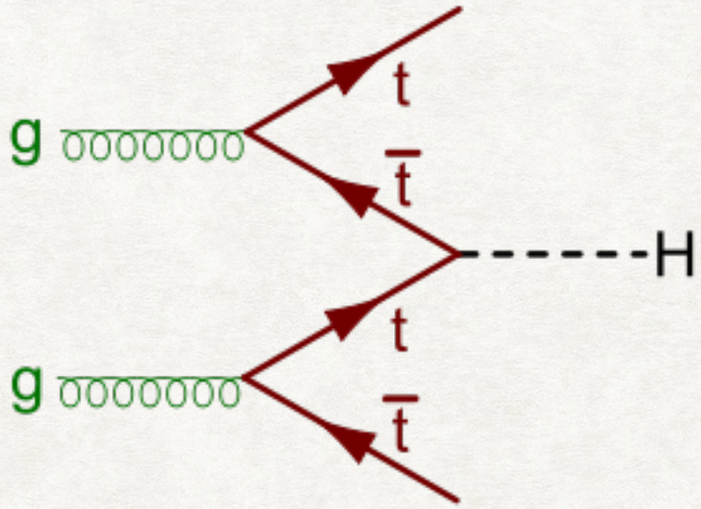
fenomenología:









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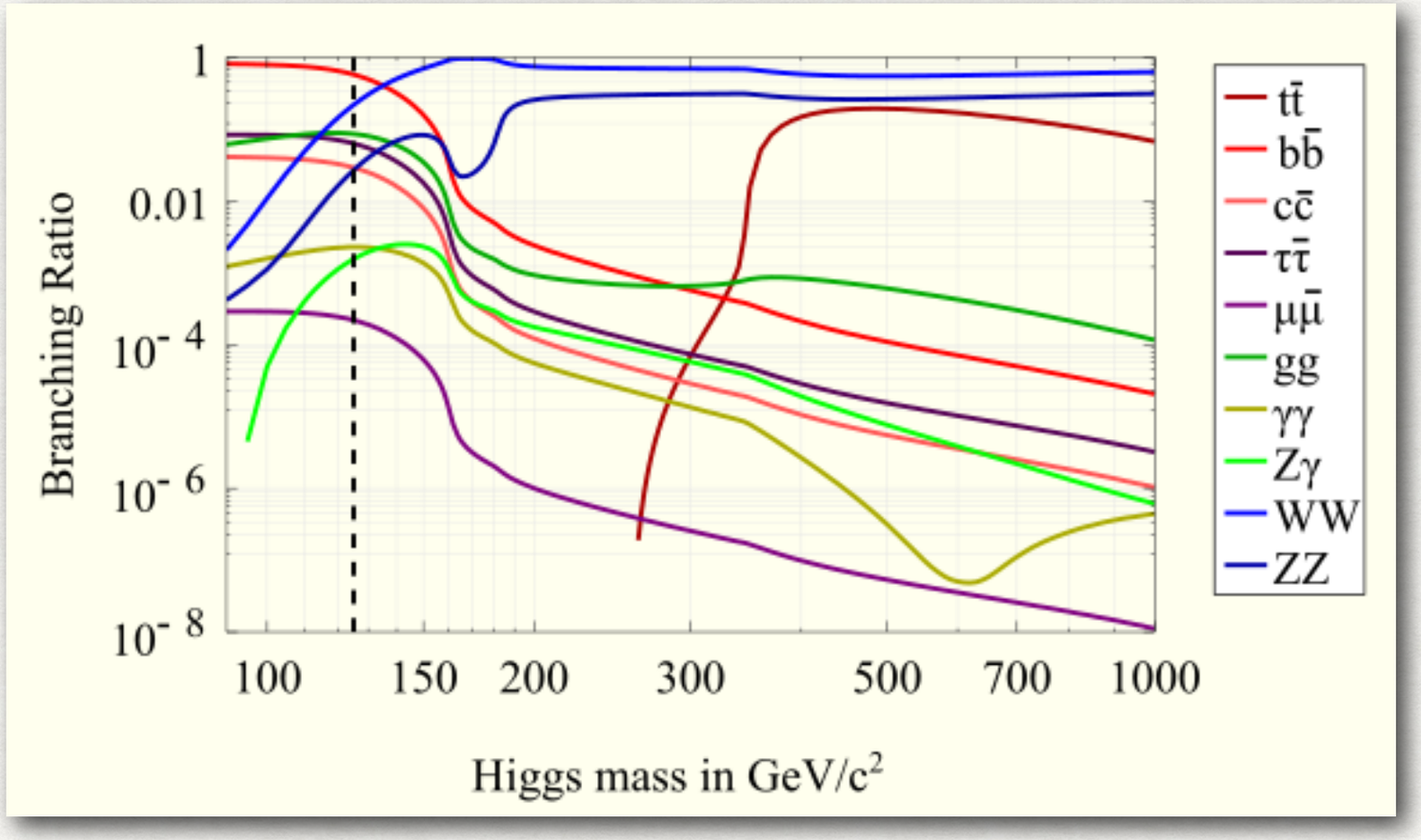
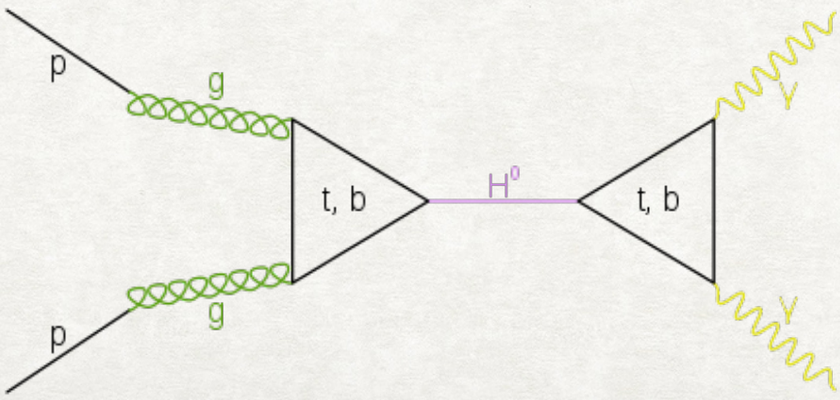
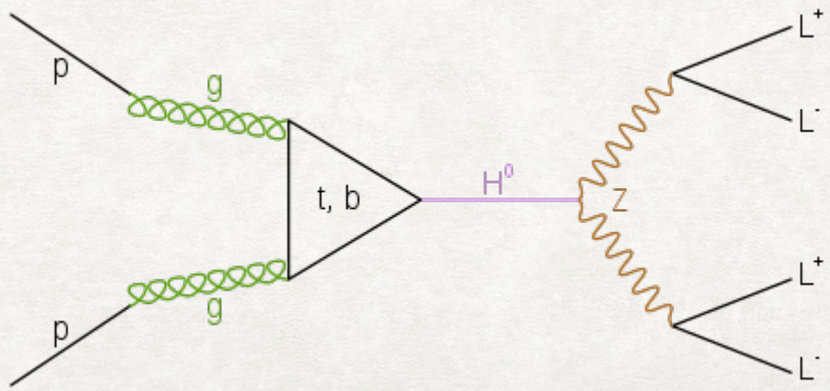
fenomenología:







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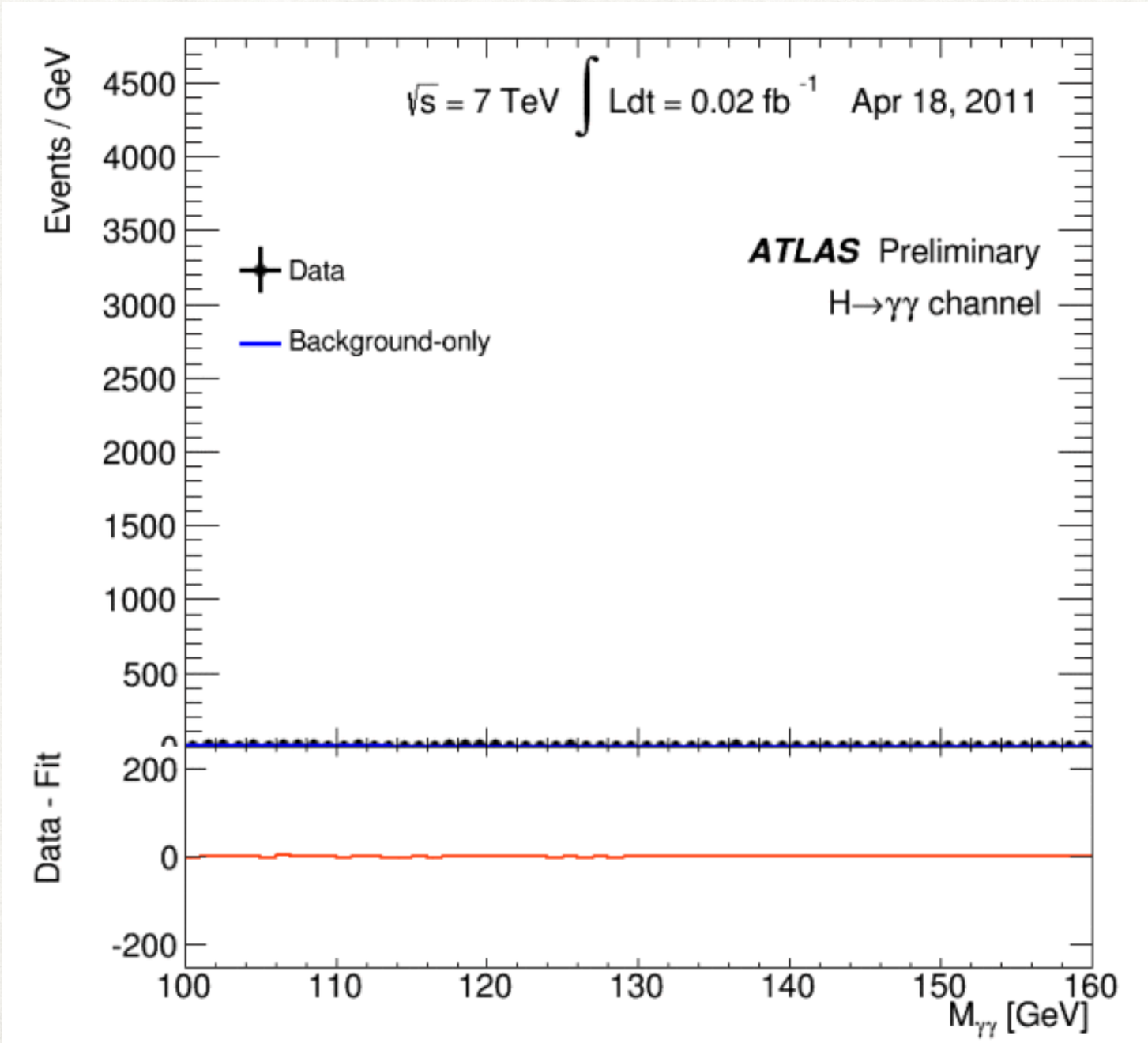
fenomenología:



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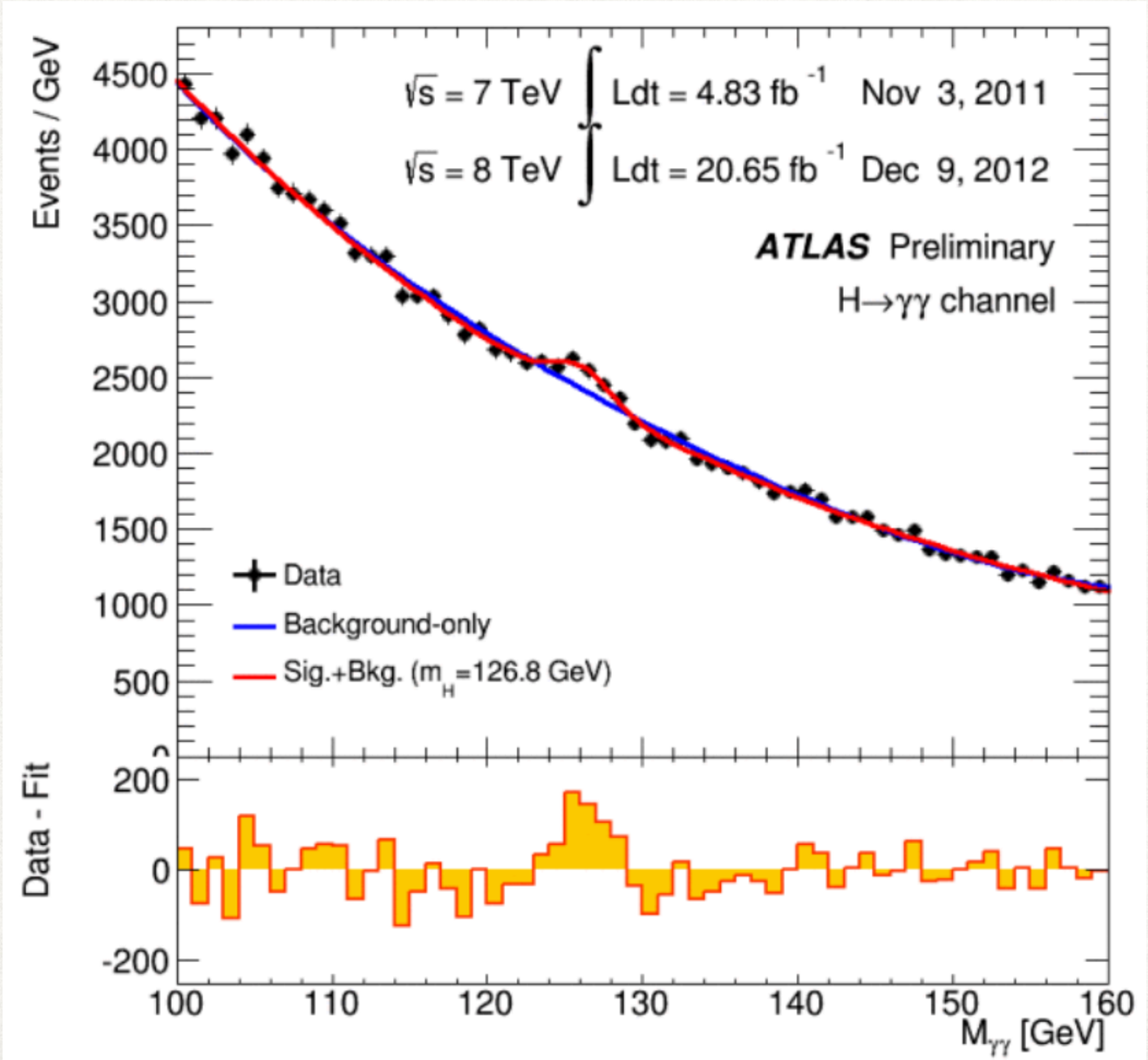
fenomenología:



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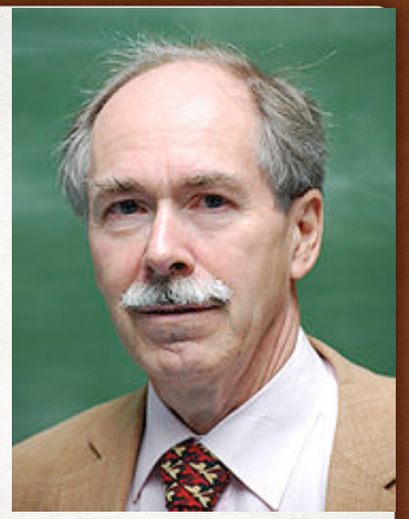

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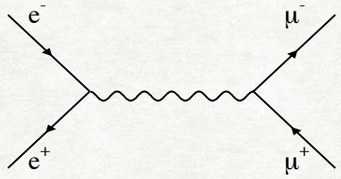
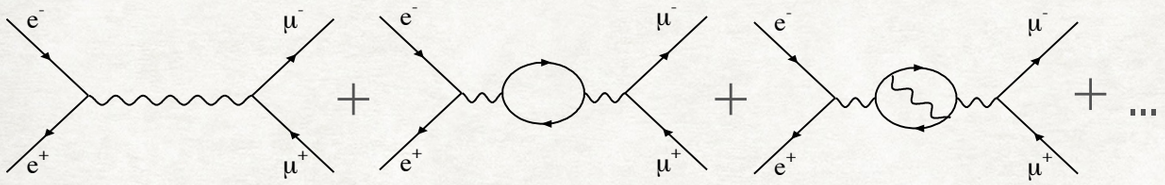
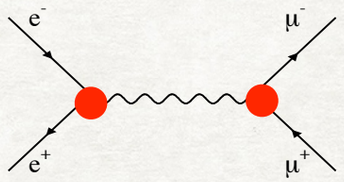
renormalizabilidad:



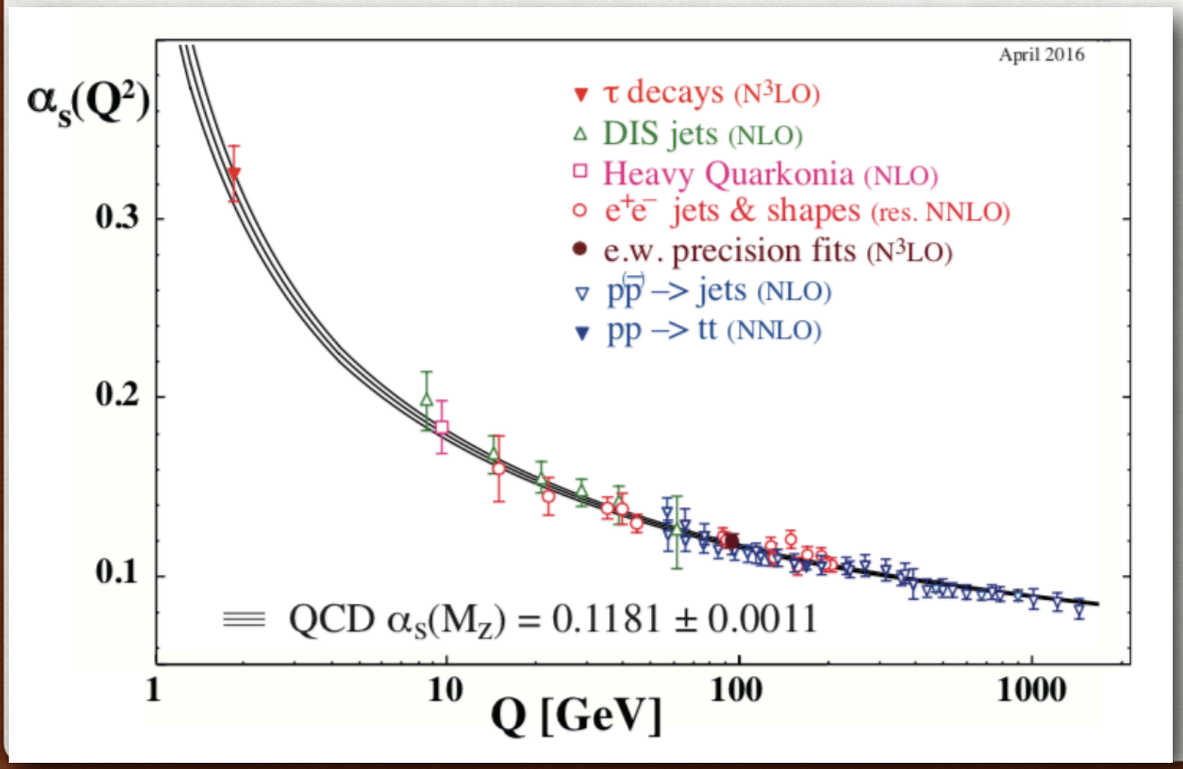
$$\sigma = \frac{4\pi}{3s}\alpha_0^2$$



$$\sigma = \frac{4\pi}{3s}\alpha_0^2(1 + \alpha_0\sigma^{(1)}(s) + \alpha_0^2\sigma^{(2)}(s) + ...)$$



$$\sigma = \frac{4\pi}{3s}\alpha_{\text{eff}}^2(s)$$



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