

# FISICA DE LAS INTERACCIONES FUNDAMENTALES

1ER CUATRIMESTRE 2026

CLASE 17

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# CLASE 17: Generación de masas en la teoría electrodébil.

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

campos de gauge:

$$W_\mu^a \longrightarrow W_\mu^a + \frac{1}{g} \partial_\mu \alpha^a - f_{abc} \alpha^b W_\mu^c$$

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

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

$$\begin{cases} \Psi_L^e \longrightarrow \Psi_L'^e = e^{i\alpha_i(x)T_i + i\beta(x)Y} \Psi_L^e \\ e_R \longrightarrow e'_R = e^{i\beta(x)Y} e_R \end{cases} \quad \Psi_L^e = \begin{pmatrix} \nu_e \\ e \end{pmatrix}_L \quad \begin{matrix} T = \frac{1}{2} & Y = -1 \\ T = 0 & Y = -2 \end{matrix} \quad Q = T^3 + \frac{Y}{2}$$

$$J_\mu^i \equiv \bar{\Psi}_L \gamma_\mu T^i \Psi_L \quad \sim g J_\mu^i W_i^\mu$$

$$J_\mu^Y \equiv \bar{e} \gamma_\mu Y e \quad \sim \frac{g'}{2} J_\mu^Y B^\mu$$

p. ej.

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

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

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

$$J_\mu^{em} = J_\mu^3 + \frac{1}{2} J_\mu^Y \quad J_\mu^3 = (\bar{\nu}_e, e_L) \frac{\gamma_\mu}{2} \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \begin{pmatrix} \nu_e \\ e_L \end{pmatrix} = \frac{1}{2} \bar{\nu}_e \gamma_\mu \nu_e - \frac{1}{2} \bar{e}_L \gamma_\mu e_L$$

$$\frac{1}{2} J_\mu^Y = -\frac{2}{2} \bar{e}_R \gamma_\mu e_R - \frac{1}{2} \bar{e}_L \gamma_\mu e_L - \frac{1}{2} \bar{\nu}_e \gamma_\mu \nu_e$$

$$J_\mu^{em} = -\bar{e}_R \gamma_\mu e_R - \bar{e}_L \gamma_\mu e_L$$

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campos de gauge:

$$\sim g J_\mu^i W_i^\mu + \frac{g'}{2} J_\mu^Y B^\mu = \underbrace{g J_\mu^1 W_1^\mu + g J_\mu^2 W_2^\mu}_{W_\mu^+, W_\mu^-} + \underbrace{g J_\mu^3 W_3^\mu + \frac{g'}{2} J_\mu^Y B^\mu}_{A_\mu, Z_\mu}$$

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

$$\begin{aligned} g J_\mu^3 W_3^\mu + \frac{g'}{2} J_\mu^Y B^\mu &= g J_\mu^3 (A^\mu \sin \theta_W + Z^\mu \cos \theta_W) + \frac{g'}{2} J_\mu^Y (A^\mu \cos \theta_W - Z^\mu \sin \theta_W) \\ &= A^\mu \underbrace{\left( g \sin \theta_W J_\mu^3 + \frac{g'}{2} \cos \theta_W J_\mu^Y \right)}_{J_\mu^{em} = J_\mu^3 + \frac{1}{2} J_\mu^Y} + Z^\mu \left( g \cos \theta_W J_\mu^3 - \frac{g'}{2} \sin \theta_W J_\mu^Y \right) \end{aligned}$$

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

$$= e A^\mu J_\mu^{em} + \frac{e}{\sin \theta_W \cos \theta_W} Z^\mu (\cos^2 \theta_W J_\mu^3 - \sin^2 \theta_W J_\mu^Y)$$

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

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## campos de gauge:

$$\mathcal{L}_1 = \bar{\Psi}_L \gamma^\mu \underbrace{[i\partial_\mu + gT^i W_\mu^i + \frac{g'}{2} Y B_\mu]}_{iD_\mu^{SU(2)_L \times U(1)_Y}} \Psi_L + \bar{e}_R \gamma^\mu \underbrace{[i\partial_\mu + \frac{g'}{2} Y B_\mu]}_{iD_\mu^{U(1)_Y}} e_R \quad \mathcal{L}_2 = -\frac{1}{4} W_{\mu\nu}^i W_i^{\mu\nu} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu}$$

$$\mathcal{L}_3 = (D_\mu \Phi)^\dagger (D^\mu \Phi) - V(\Phi) = (\partial_\mu - \underline{i g T^i W_\mu^i - i \frac{g'}{2} B_\mu})^\dagger \Phi^\dagger (\partial_\mu - i g T^i W_\mu^i - i \frac{g'}{2} B_\mu) \Phi - V(\Phi) \quad (Y = 1)$$

$$\Phi = \frac{1}{\sqrt{2}} \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h(x) \end{pmatrix} e^{iT^i \theta_i(x)} \quad \left| (-i g T^i W_\mu^i - i \frac{g'}{2} B_\mu) \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v \end{pmatrix} \right|^2 = \frac{1}{2} v^2 \frac{1}{4} \left| (g \sigma^i W_\mu^i + g' B_\mu) \begin{pmatrix} 0 \\ 1 \end{pmatrix} \right|^2$$

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

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

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

$$g \sin \theta_W = g' \cos \theta_W = e \quad M_Z = \frac{M_W}{\cos \theta_W} \quad M_Z = 91.2 \text{ GeV} \quad \begin{cases} A_\mu \equiv B_\mu \cos \theta_W + W_\mu^3 \sin \theta_W \\ Z_\mu^0 \equiv -B_\mu \sin \theta_W + W_\mu^3 \cos \theta_W \end{cases}$$

$$v \sim 246 \text{ GeV} \quad \theta_W \sim 30^\circ \quad M_W = 79.69 \text{ GeV}$$

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## campos fermiónicos:

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

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

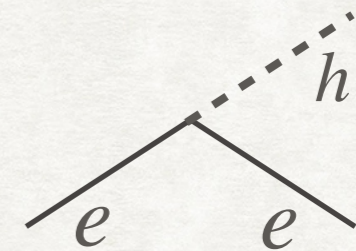
$m_e$

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

$$m_e = 0.511 \text{ MeV}$$

$$v \sim 246 \text{ GeV}$$

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

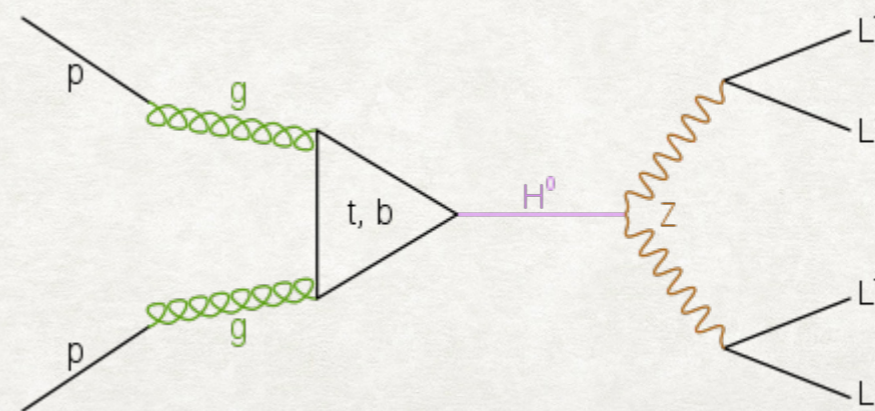
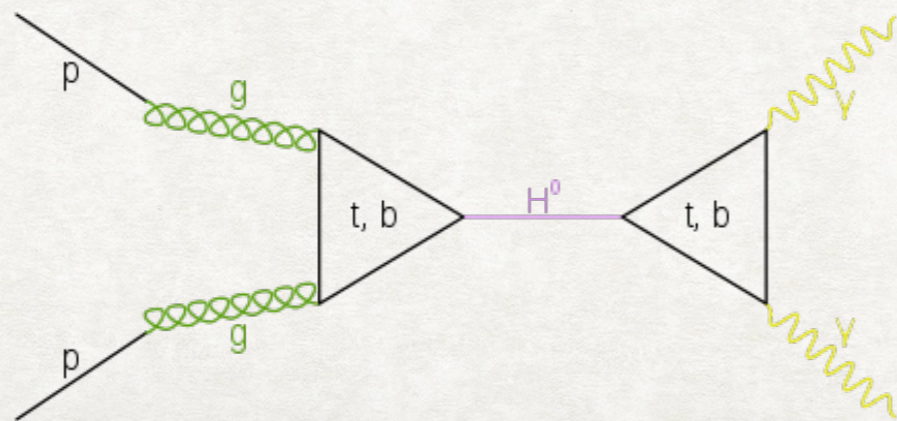


$$m_t = 174 \text{ GeV}$$

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

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

$$m_h \sim 125 \text{ GeV}$$



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## campos fermiónicos:

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

$$= - \underbrace{\frac{G_e}{\sqrt{2}} \nu (\bar{e}_L e_R + \bar{e}_R e_L)}_{m_e} - \frac{G_e}{\sqrt{2}} h (\bar{e}_L e_R + \bar{e}_R e_L) \quad m_\nu = 0$$

$$\mathcal{L}_5 = -G_d \left[ (\bar{u}, \bar{d}')_L \Phi d'_R + \bar{d}'_R \bar{\Phi} \begin{pmatrix} u \\ d' \end{pmatrix}_L \right] - G_u \left[ (\bar{u}, \bar{d}')_L \tilde{\Phi} u_R + \bar{u}_R \tilde{\Phi} \begin{pmatrix} u \\ d' \end{pmatrix}_L \right]$$

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

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

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

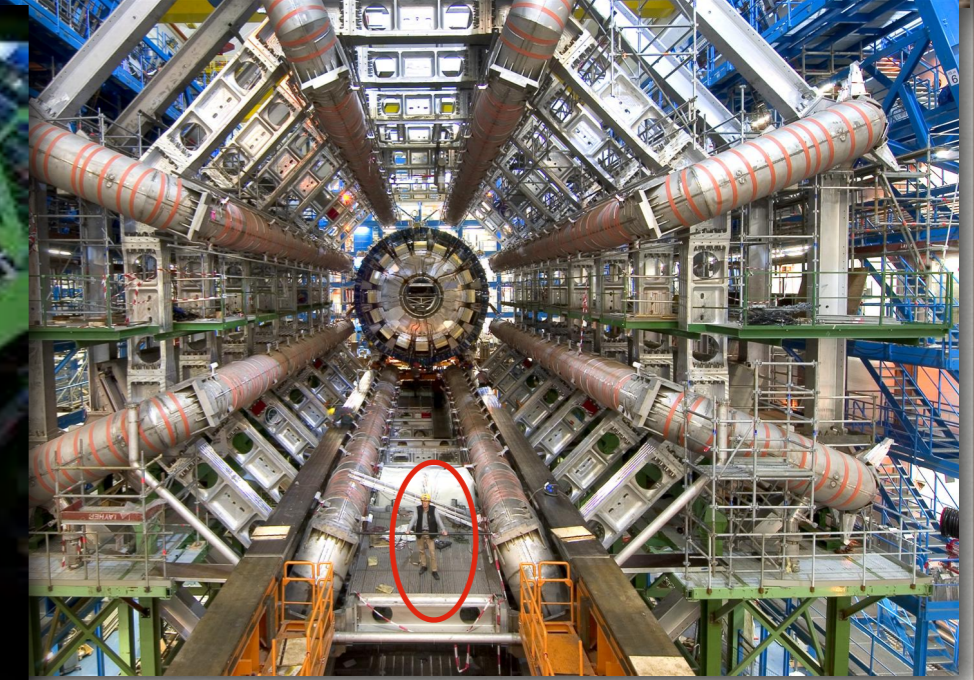
~200 GeV

~14 TeV

2009 LHC startup

2012 discovery

2013 Nobel

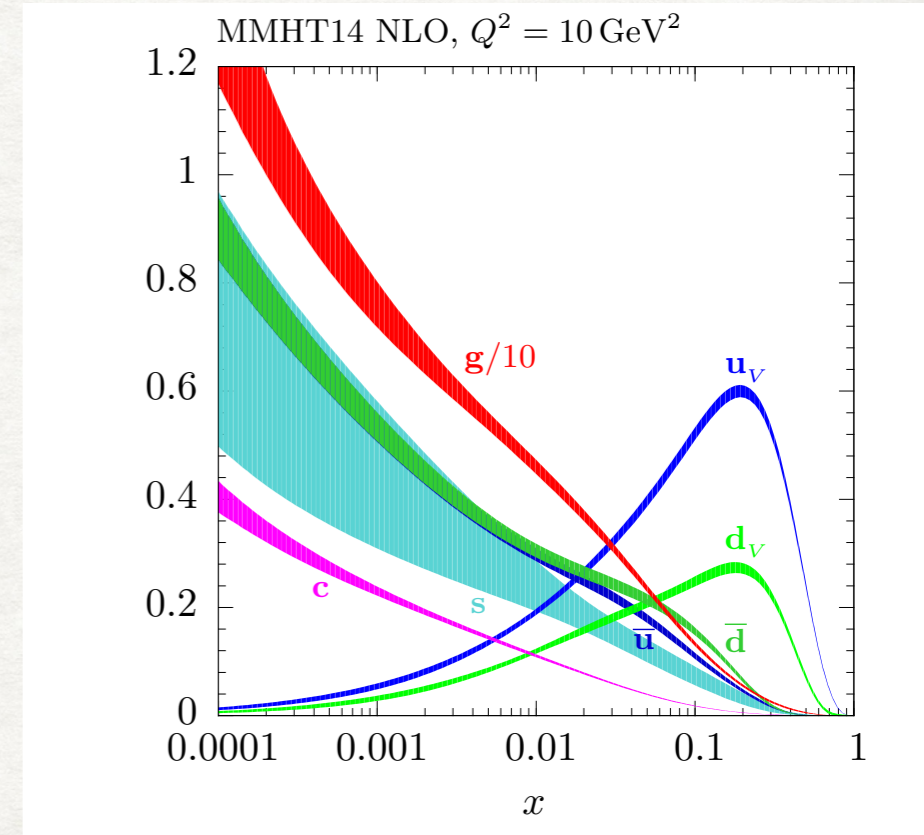
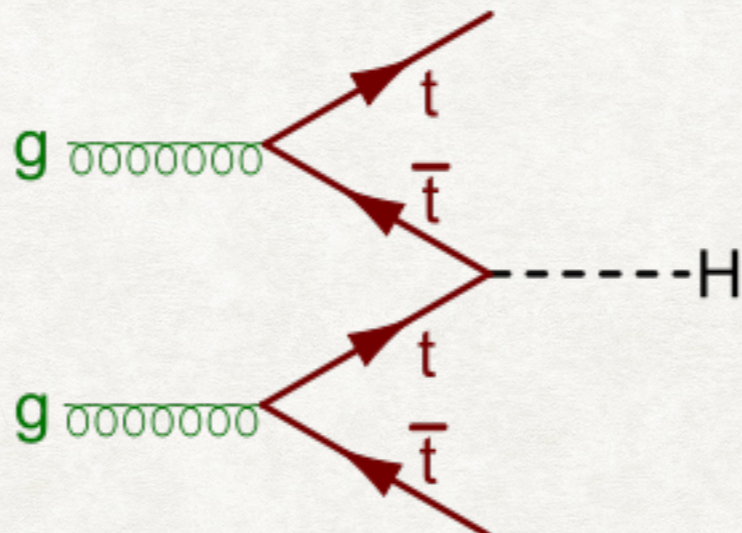
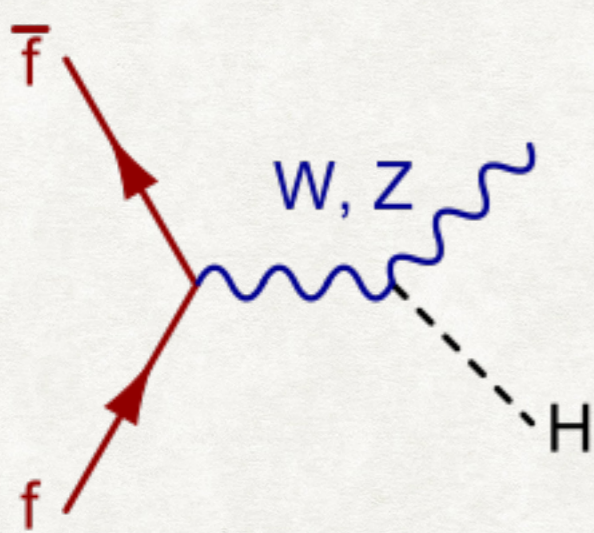
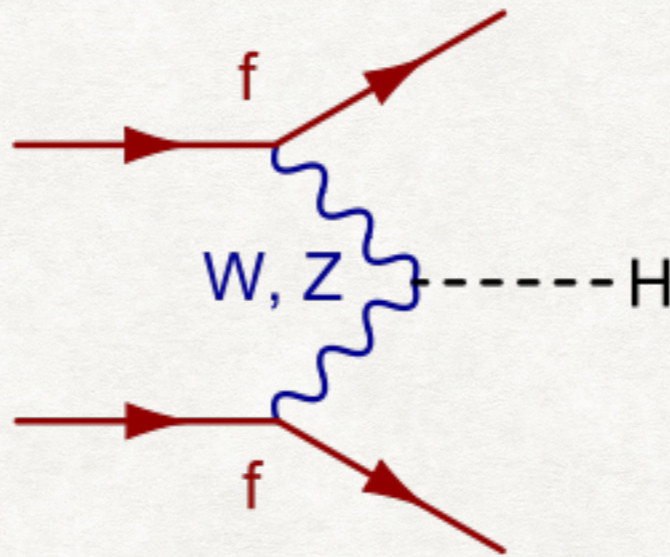
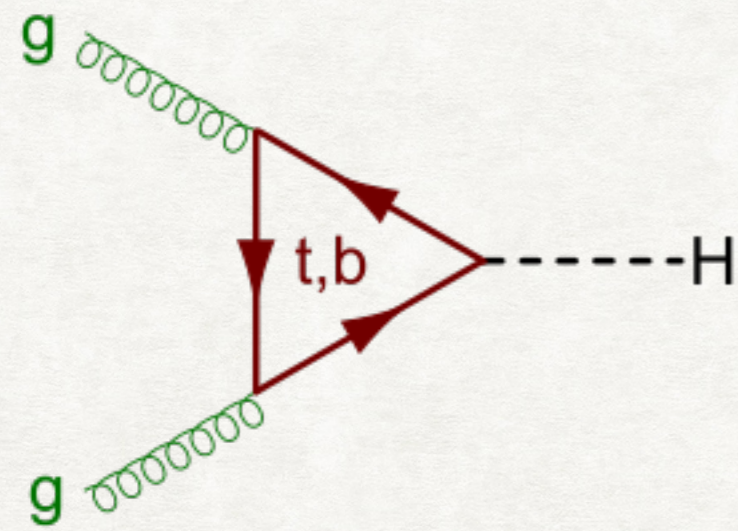


2025 sin señales de nueva física



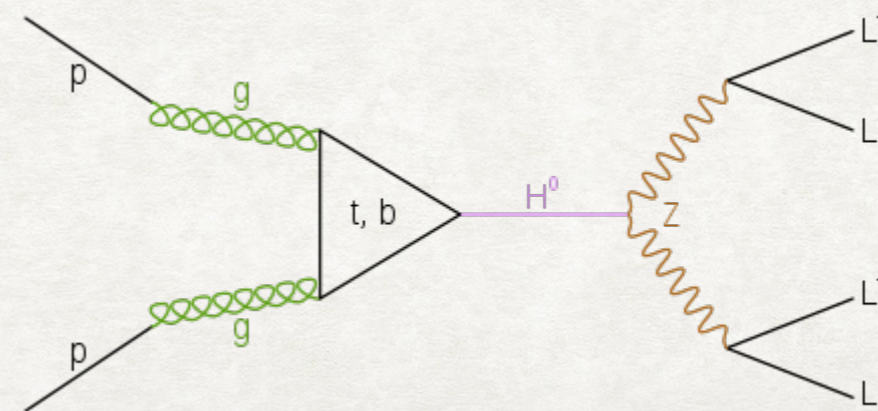
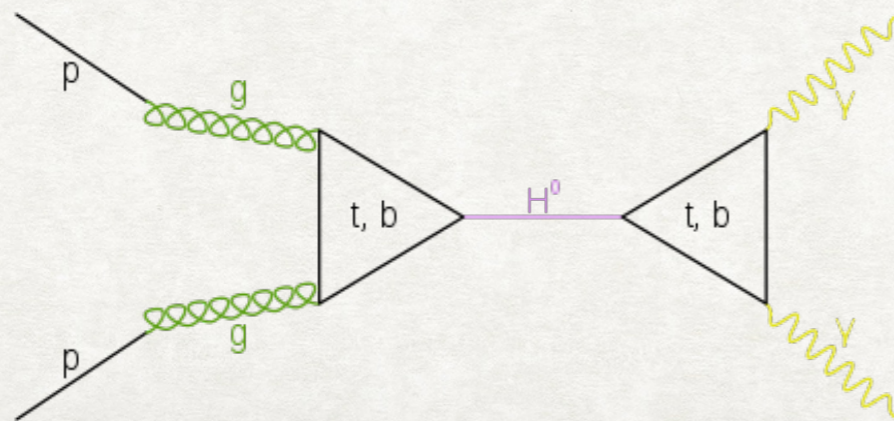
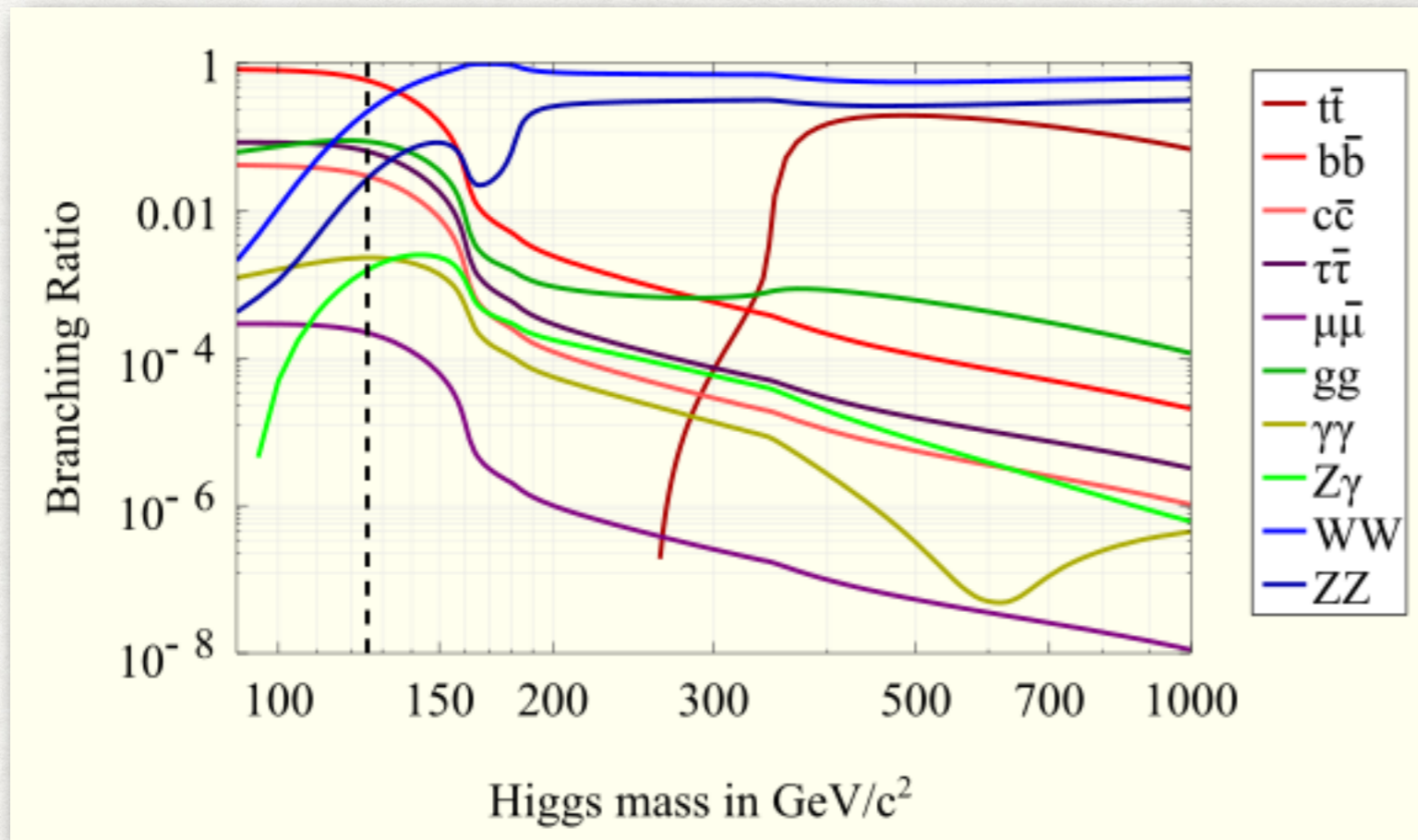
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fenomenología:



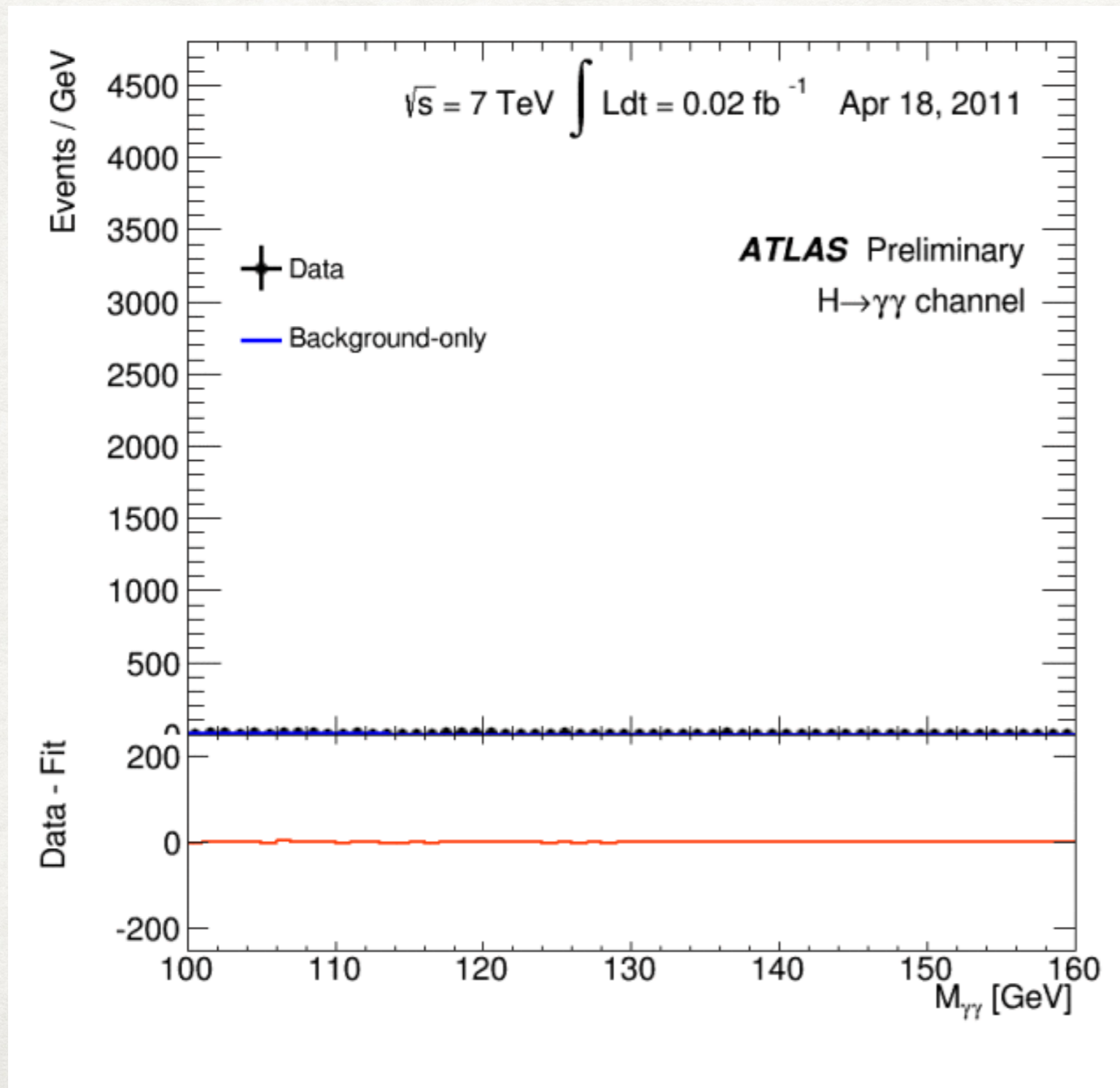
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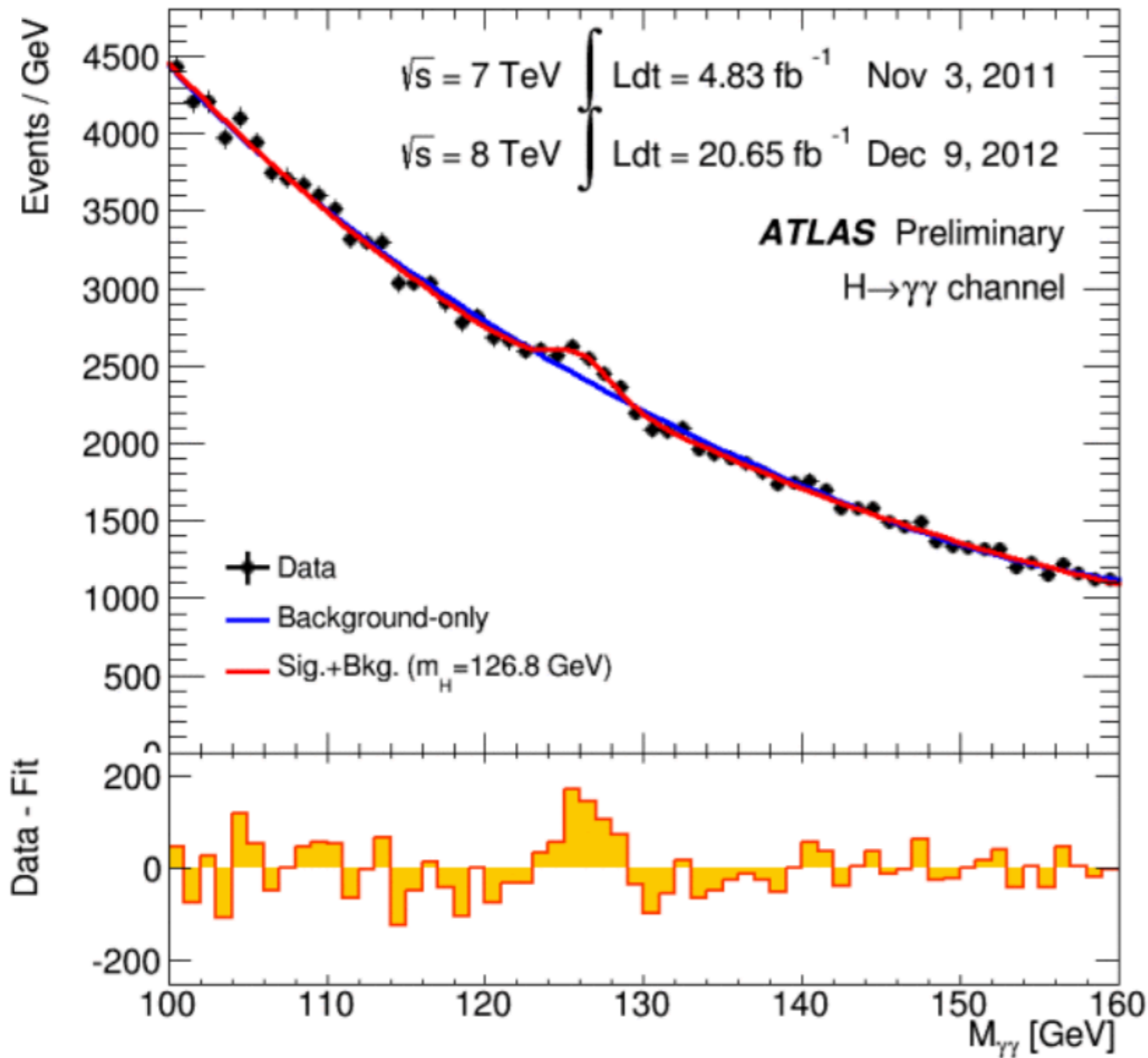
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fenomenología:



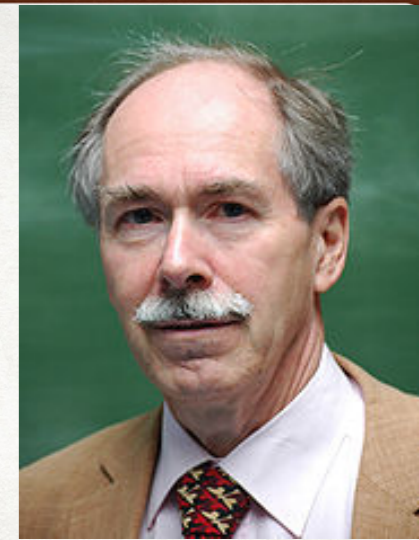
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fenomenología:

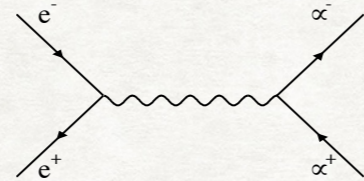


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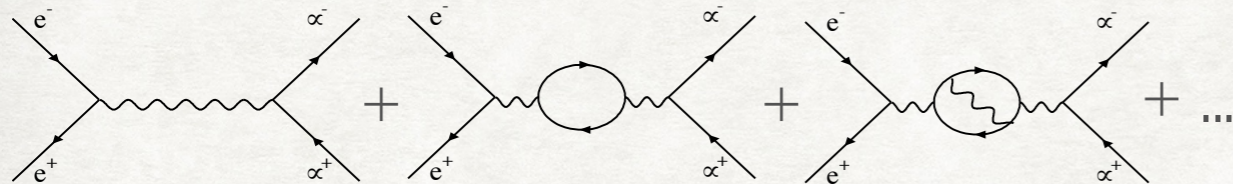
renormalizabilidad:



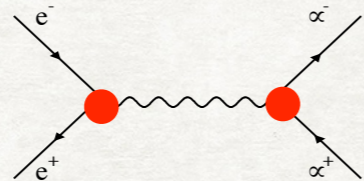
G. 't Hooft



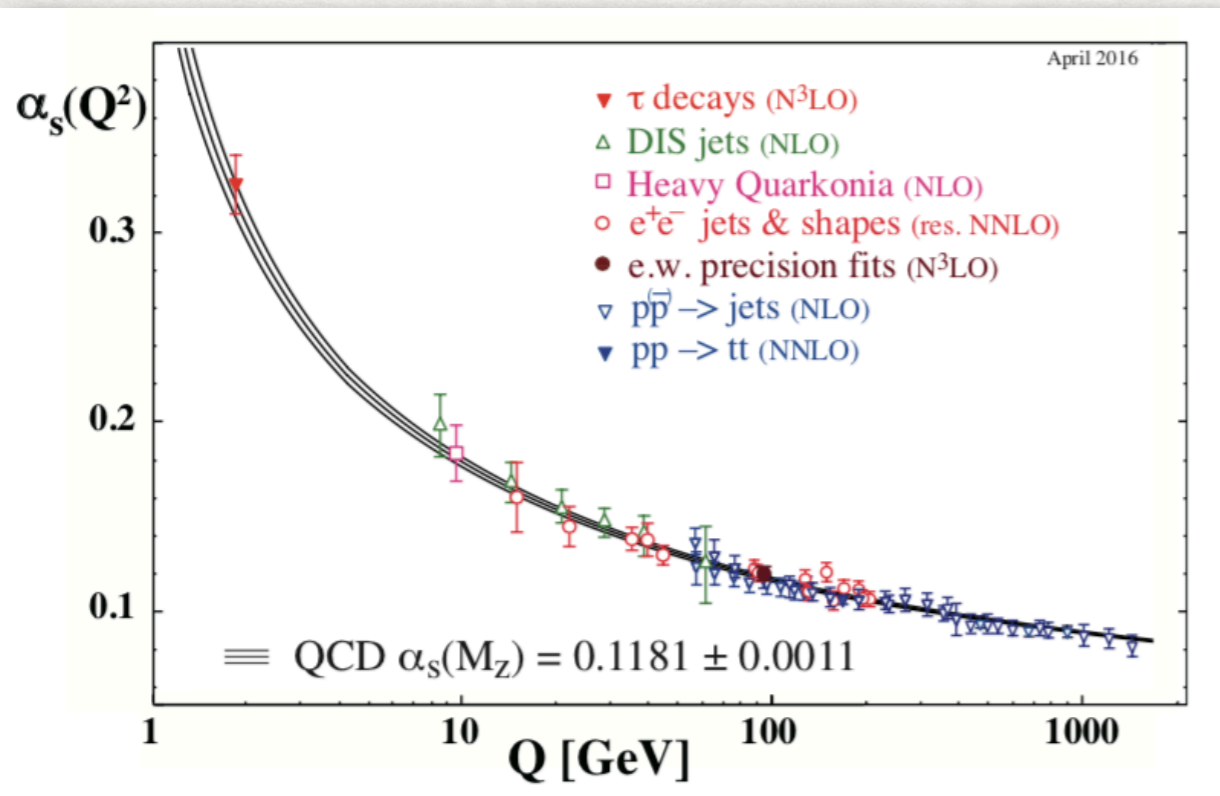
$$\sigma = \frac{4\pi}{3s} \alpha_0^2$$



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



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



J.J. Giambiaggi G. Bollini

