Übungen zu Physik an Hadron-Collidern SS 2013
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Übungsblatt Nr. 8

Die Lösungen müssen bis 11 Uhr am Mittwoch, 26.6.2013 in die Briefkästen im Erdgeschoss des Gustav-Mie-Hauses eingeworfen werden!

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1. **Dirac Lagrangian density and local gauge invariance**

   Consider the following Lagrangian density:

   $$L = i\bar{\psi}\gamma_\mu\partial^\mu\psi - m\bar{\psi}\psi \tag{1}$$

   - Obtain the Dirac equation by making use of the Euler-Lagrange equation **[1 point]**:

   $$\partial_\mu\left(\frac{\partial L}{\partial(\partial_\mu\bar{\psi})}\right) = \frac{\partial L}{\partial\bar{\psi}} \tag{2}$$

   - Show that the Lagrangian density L is invariant under *global* $U(1)$ transformations **[1 point]**:

   $$\psi \to e^{i\alpha}\psi \tag{3}$$

   - Show that the L is *not* invariant under *local* $U(1)$ gauge transformations **[2 points]**:

   $$\psi \to e^{i\alpha(x)}\psi \tag{4}$$

   - Show that the modified Lagrangian density obtained introducing a new vector field A_μ:

   $$L = i\bar{\psi}\gamma_\mu\partial^\mu\psi - m\bar{\psi}\psi + e\bar{\psi}\gamma^\mu A_\mu\psi - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} \tag{5}$$

   (where $F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$) is invariant under local $U(1)$ gauge transformations, if A_μ transforms as follows **[2 points]**:

   $$A_\mu \to A_\mu + (1/e)\partial_\mu\alpha \tag{6}$$

   - Show that a mass term for the vector field $m^2 A_\mu A^\mu$ would violate the gauge local invariance **[1 point]**.

   In short: the requirement of local gauge invariance "produces" the interaction term between fermions and bosons, but only for massless bosons....

2. **Higgs boson at the LHC**

   A Higgs boson has been discovered at the LHC with a mass of about 126 GeV. The dominant production mode is gluon fusion, $gg \to H$. At the mass of 126 GeV the Higgs boson decays predominantly into a pair of b quarks, $H \to b\bar{b}$. However, this is a very difficult channel to probe. In the following this should be understood in a semi-quantitative way.

   - Find out in the literature what is the production cross section for the Higgs boson at the LHC at a centre-of-mass energy of 8 TeV **[1 point]**.
   - Make a list of the main background processes and corresponding (approximate) cross sections for a possible $H \to b\bar{b}$ search via the production in gluon fusion **[2 point]**.

- Assuming that the cross section for producing $b\bar{b}$ in the final state via QCD production for the selected final state is 100 nb, and that of the Higgs is 1 pb, compute the signal statistical significance $N_s/\sqrt{N_b}$ for data corresponding to 1 fb^{-1} of integrated luminosity. For what integrated luminosity one would reach a statistical significance of 5σ **[2 points]**
- Please discuss to what extent the other production modes (vector boson fusion (VBF), associated production via vector bosons (VH)) can be used to search for the $H \to b\bar{b}$ decay. **[1 point]**
- What decay channels of the accompanying vector bosons, in the VH case, can be exploited to reach an acceptable signal-to-background ratio. **[1 point]**