TÉCNICO LISBOA

2^{nd} exam

January 27th 2015: 15H00

Duration of the test: 1H30

Duration of the exam: 3H00

Mestrado em Eng. Física Tecnológica (MEFT)
Particle Physics
1^{st} semester of 2014-15

Prof. Mário Pimenta
Prof. Jorge Romão
Dr. Ruben Conceição

- The allowed elements for consult during the exam are:
  - the PDG (Particle Data Book)
  - one single A4 page with formulas.
- Clearly identify all pages of the exam.
- The exam has 4 questions (3 pages).

1^{st} test

1. **[5 val]** The CDF experiment at the proton anti-proton Tevatron collider had around the interaction region a tracking detector system composed by a silicon micro vertex detector emersed in a magnetic field of 1.4T aligned in the beam direction.

Consider that in the primary vertex of the $p\overline{p}$ collision a B^+ meson was formed and decayed into $B^+ \to J/\Psi\, K^+$.

a) Write the quark constituints of the B^+ decay.

b) Verify if the following decays are possible and if not explain why:

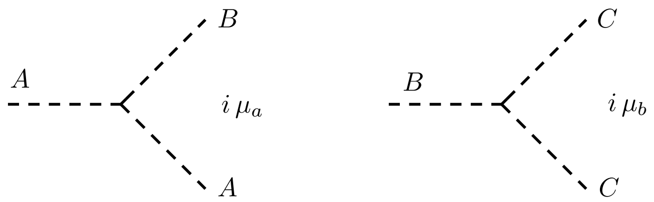
i. $B^+ \to e^+\overline{\nu_e}$ ii. $B^+ \to p\pi^0$ iii. $B^+ \to p\overline{\Lambda}\pi^0$

c) What is the energy range that the B^+ meson should have in order that the secondary vertex (B^+ decay) occurs often inside of the tracker. Consider that the B^+ was emitted at 30°, with respect to the beam axis, and the tracker is a cylinder with $r_{min} = 1.5\,\text{cm}$ and $r_{max} = 137\,\text{cm}$.

d) Knowing that the main decay of $J/\Psi \to \mu^-\mu^+$ and that the J/Ψ has an energy of 93 GeV determine the minimum and maximum energy, E_{min} and E_{max}, that each muon from the J/Ψ decay can carry. Determine also the range for the muon emission angle, θ_{min} and θ_{max}.

e) Discuss how the invariant mass of the J/Ψ could be determined from the momentum of the detected muons.

2. **[5 val]** Consider a theory with three neutral scalars A, B, C (spin 0). They interact in such way that the Feynman rules for the interactions are



where μ_a and μ_b have dimensions of mass ($\hbar = c = 1$). The masses are such that $m_B > m_C$ and $m_B > 2m_A$.

a) Find the total width $\Gamma(B \to A + A)$ as a function of the masses of the particles.

b) For the process $A + C \to A + C$ draw the diagram(s) that contribute in lowest order and write down the amplitude(s).

c) Find the differential cross section $d\sigma/d\Omega$ in the CM frame as a function of the Madelstam variable $s = (p_1 + p_2)^2$, the scattering angle θ and the masses of the particles.

d) In the limit $m_B \gg \sqrt{s}, m_A, m_C$ make the corresponding approximations and evaluate the total cross section in the CM frame.

e) Verify that you could have obtained this result, up to a numerical factor, by dimensional analysis.

2^{nd} *test*

3. **[8 val]** The Tevatron was an accelerator where protons and antiprotons beams with the same energy collided head-on. Consider the detection of a W^- through the following process

$$p + \overline{p} \to W^- \to e^-(p_3) + \overline{\nu}_e(p_4)$$

a) Consider the elementary process that is at its origin at the quark level,

$$q(p_1) + \overline{q'}(p_2) \to W^- \to e^-(p_3) + \overline{\nu}_e(p_4)$$

Identify the valence quarks q and $\overline{q'}$.

b) Draw the Feynman diagram(s) that contribute in the Standard Model, in lowest order, to this process.

c) Write down the amplitude. Neglect all fermion masses.

d) Show that if one neglects the fermions masses one can also neglect the terms proportional to the momenta in the numerator of the Feynman propagator for the massive gauge bosons. Write down the simplified amplitude.

e) Write down the non-vanishing helicity amplitudes for this process with the previous assumptions.

f) Calculate the spin averaged amplitude $\langle|\mathcal{M}|^2\rangle$ and write the expression for the differential cross section $d\sigma/d\Omega$ in the CM frame in terms of the energy in the CM frame for this elementary process $\hat{s}$.

g) Evaluate the total cross section in the CM frame $\sigma(\hat{s})$.

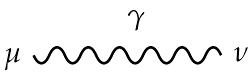
h) Write the amplitude for the process $p\overline{p} \to W \to e^-\overline{\nu}_e$ as a function of the elementary cross-section, calculated above, and taking into account only the PDFs of the valence quarks. Note: no calculations are necessary.

4. **[2 val]** At Tevatron it was discovered the top quark that was missing to complete the quark sector of the standard model. Consider the single top production in the collision of $p\overline{p}$ at $\sqrt{s} = 1.96\,\text{TeV}$.

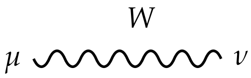
a) Draw the first order Feynman diagram in the s-channel for the single top production at Tevatron.

b) Describe the possible final states that could be observed experimentally and discuss which channels have a more easy experimental signature.

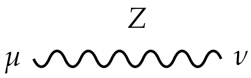
Propagators



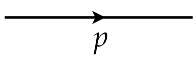
$$-i\frac{g_{\mu\nu}}{k^2} \tag{1}$$



$$-i\frac{g_{\mu\nu} - \frac{k_\mu k_\nu}{M_W^2}}{k^2 - M_W^2 + i\,M_W\Gamma_W} \tag{2}$$



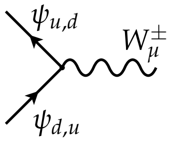
$$-i\frac{g_{\mu\nu} - \frac{k_\mu k_\nu}{M_Z^2}}{k^2 - M_Z^2 + i\,M_Z\Gamma_Z} \tag{3}$$



$$\frac{i(\not{p} + m_f)}{p^2 - m_f^2} \tag{4}$$

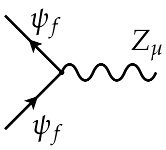
Vertices

Charged Current

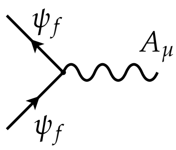


$$-i\frac{g}{\sqrt{2}}\gamma_\mu\frac{1-\gamma_5}{2} \tag{5}$$

Neutral Current



$$-i\frac{g}{\cos\theta_W}\gamma_\mu\left(g_V^f - g_A^f\gamma_5\right)$$



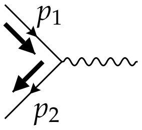
$$-ieQ_f\gamma_\mu \tag{6}$$

where

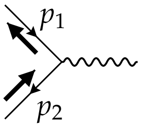
$$g_V^f = \frac{1}{2}T_f^3 - Q_f\sin^2\theta_W, \quad g_A^f = \frac{1}{2}T_f^3\,. \tag{7}$$

Results for the Helicity Currents

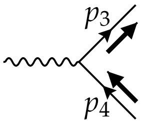
s-channel



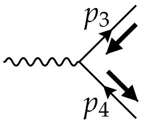
$$J_{u_1v_2}(\uparrow,\downarrow) = \sqrt{s}\,(0,-1,-i,0) \tag{8}$$



$$J_{u_1v_2}(\downarrow,\uparrow) = \sqrt{s}\,(0,-1,i,0) \tag{9}$$

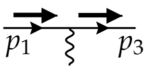


$$J_{u_3v_4}(\uparrow,\downarrow) = \sqrt{s}\,(0,-\cos\theta,i,\sin\theta) \tag{10}$$

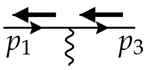


$$J_{u_3v_4}(\downarrow,\uparrow) = \sqrt{s}\,(0,-\cos\theta,-i,\sin\theta) \tag{11}$$

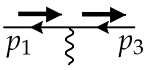
t-channel



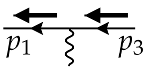
$$J_{u_1u_3}(\uparrow,\uparrow) = \sqrt{s}\,\left(\cos\frac{\theta}{2},\sin\frac{\theta}{2},i\sin\frac{\theta}{2},\cos\frac{\theta}{2}\right) \tag{12}$$



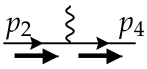
$$J_{u_1u_3}(\downarrow,\downarrow) = \sqrt{s}\,\left(\cos\frac{\theta}{2},\sin\frac{\theta}{2},-i\sin\frac{\theta}{2},\cos\frac{\theta}{2}\right) \tag{13}$$



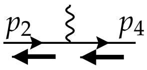
$$J_{v_1v_3}(\uparrow,\uparrow) = \sqrt{s}\,\left(\cos\frac{\theta}{2},\sin\frac{\theta}{2},i\sin\frac{\theta}{2},\cos\frac{\theta}{2}\right) \tag{14}$$



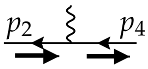
$$J_{v_1v_3}(\downarrow,\downarrow) = \sqrt{s}\,\left(\cos\frac{\theta}{2},\sin\frac{\theta}{2},-i\sin\frac{\theta}{2},\cos\frac{\theta}{2}\right) \tag{15}$$



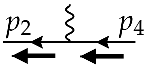
$$J_{u_2u_4}(\uparrow,\uparrow) = \sqrt{s}\,\left(\cos\frac{\theta}{2},-\sin\frac{\theta}{2},i\sin\frac{\theta}{2},-\cos\frac{\theta}{2}\right) \tag{16}$$



$$J_{u_2u_4}(\downarrow,\downarrow) = \sqrt{s}\,\left(\cos\frac{\theta}{2},-\sin\frac{\theta}{2},-i\sin\frac{\theta}{2},-\cos\frac{\theta}{2}\right) \tag{17}$$



$$J_{v_2v_4}(\uparrow,\uparrow) = \sqrt{s}\,\left(\cos\frac{\theta}{2},-\sin\frac{\theta}{2},i\sin\frac{\theta}{2},-\cos\frac{\theta}{2}\right) \tag{18}$$



$$J_{v_2v_4}(\downarrow,\downarrow) = \sqrt{s}\,\left(\cos\frac{\theta}{2},-\sin\frac{\theta}{2},-i\sin\frac{\theta}{2},-\cos\frac{\theta}{2}\right) \tag{19}$$