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Subatomic physics

Final exam

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Handtekening:

By uploading the results of this exam, I declare that I have taken this exam myself, without the help of other persons or other aids than the textbook / lecture notes / my own notes.

Signature:

General information

- Add your name and student ID on every sheet you plan to hand in
- Write as clear as possible
- Use the white exam sheets to hand in your answers for all the questions. This applies also to the multiple choice exercise, in any!!!
- Do not give final answers only, explain your reasoning (short) and give full calculations except for the multiple choice questions of course (if applicable)
- A simple calculator use is allowed (not programmable).
- Do not use mobile/smart phones, groups, chats etc!
- The points of each question are indicated in brackets at its end.

Sending your answers back

- Scan or take a photo of every sheet you want to hand in.
- Make sure that all of them are visible and with the right angle
- Merge all the sheets in one single file
- Send the file or (preferably) the link to the file by mail: P.Christakoglou@uu.nl

Exercise 1

(a) Is a real particle space-like, time-like or light-like and why? Similarly for a massless particle. **(1)**

(b) Photons can undergo a process called pair production. How would you reconstruct and identify the final products? **(1)**

(c) What is Noether's theorem and why is it so important? **(1)**

(d) What do the solutions of the Dirac equation of motion represent? **(1)**

(e) How does a typical Lagrangian density look for spin-1 gauge bosons and how does it look for a fermion ? **(1)**

(f) The Standard Model describes three out of the four fundamental forces of nature. Order the corresponding coupling constants as measured at "room" temperature, starting from the weakest and ending up to the largest. **(1)**

(g) Two protons are separated by a distance larger than their radius. Considering your answer to the previous question about the values of the coupling constants of the three theories, argue about which force will the two protons feel the most and why. **(1)**

Exercise 2

(a) One of the possible future directions of CERN is to have a physics program based on the acceleration of proton beams at a momentum of 50 TeV. The main scientific motivation is the search for particles associated with physics beyond the standard model with mass by far larger than the mass of the Higgs ($m_H \approx 125$ GeV). In the hypothetical case that you are responsible of selecting between to design an experiment operating in

1. a collider mode with each proton beam being accelerated up to $P = 50$ TeV,
2. a fixed target mode where a proton beam accelerated up to $P = 50$ TeV collides with a proton target

what would be your choice and why? **(1)**

(b) In 2013, for the first time at the LHC a proton beam accelerated at an energy of 4 TeV collided onto fully stripped $^{208}_{82}$Pb ions at 1.58 TeV per nucleon energy. What was the center of mass energy per nucleon pair available for particle production? **(1)**

(c) Cosmic ray muons are produced high in the atmosphere (let's say at 10000 m) and travel with a velocity close to the speed of light (let's say $v = 0.999c$). The proper lifetime of the muon is $\tau = 2.2$ μs.

1. How far does the muon travel according to its own reference frame? **(1)**
2. How far does the muon travel according to an observer at rest on Earth? **(1)**
3. Based on the two previous answers, does the muon reach the ground? Discuss if these two previous results are consistent and why. **(1)**

It is given that: $\gamma = 1/\sqrt{1-(v/c)^2} = 22.4$ and $c \approx 3 \cdot 10^8$ m/sec.

Exercise 3

(a) What is the main physical consequence of introducing local gauge invariance in the QED Lagrangian density? **(1)**

(b) Explain how the covariant derivative "works" for QED i.e. how it allows gauge invariant Lagrangians to be constructed and how the difference with the normal partial derivative achieves this. **(1)**

(c) Write down the QED Lagrangian density. Which is the term that describes the gauge boson propagators and which leads to interactions? **(1)**

(d) What are the main differences between quarks and leptons? **(1)**

Exercise 4

(a) Which experimental observations exist that show that SU(3) is the right group for QCD? **(1)**

(b) Which processes are contained in the term $\overline{\Psi}\lambda^{\alpha}\gamma_{\mu}A^{\mu,\alpha}\Psi$ of the QCD Lagrangian density? **(1)**

(c) Which are the extra terms in the non-abelian field tensor $F^{\alpha}_{\mu\nu}$ and what physical consequences do they have? **(1)**

(d) Explain the physics of the running coupling constant of QCD. **(1)**