positioning

[program=makeindex,columns=2,intoc=true,options=-s ../../general/pyro.ist] first-pagestyle=empty, othercode=

||||||

todolistitemize2 [todolist]label=

–[[Require library for Lua library]] require("lualibs.lua")

function tableMerge(t1, t2) for k,v in pairs(t2) do if type(v) == "table" then if type(t1[k] or false) == "table" then tableMerge(t1[k] or , t2[k] or) else t1[k] = v end else t1[k] = v end end return t1 end

–[[Opens the two metadata file]] local specificFile = io.open('metadata.json') local folderFile = io.open('../metadata.json') local genericFile = io.open('../../metadata.json')

–[[Reads the files]] local specificJsonString = specificFile:read('*a') local folderJsonString = folderFile:read('*a') local generalJsonString = genericFile:read('*a')

–[[Closes the files]] specificFile.close() folderFile.close() genericFile.close()

–[[Convert the Json strings in Lua dictionaries]] local specificJson = utilities.json.tolua(specificJsonString) local folderJson = utilities.json.tolua(folderJsonString) local generalJson = utilities.json.tolua(generalJsonString)

–[[Merge top layer of dictionaries, so that the specific one overrides the generic one.]]

metadata = tableMerge(tableMerge(generalJson, folderJson), specificJson)

if true then tex.print("
input
main/../../general/italian.tex") else tex.print("
input
main/../../general/english.tex") end

folFOLFirst Order Logic

–[[Load data into variables to simplify code afterwards]] title = metadata["title"] cfu = metadata["cfu"] year = metadata["year"] degree = metadata["degree"] university = metadata["university"] notesType = metadata["notesType"] professors = metadata["professors"] authors = metadata["authors"]

tex.print("
MakeUppercase
textbf
large"..title.."")

for key, value in pairs(professors) do tex.print('Prof. '..value["name"] .. " " .. value["surname"].."
") end   if cfu > 0 then tex.print(cfu.." CFU
") end

for key, value in pairs(authors) do tex.print('
textbf'..value["name"] .. " " .. value["surname"].."
") end

tex.print(notesType.."
")   tex.print(year.."
")

tex.print(degree.."
")   tex.print(university.."
")   Italy
October 16, 2017

TITLEPAGE NOT RENDERED!
RECOMPILE WITH LUATEX!

0.1 What is a Feynman diagram

A Feynman diagram is a graphical representations of the math describing the behavior of subatomic particles, as described by the quantum electrodynamics (QED) model. In the following notes, we will follow the convention that places time on the abscissas and space on the ordinates.

introduction

0.1.1 Electron

An electron e^- (Figure fig:electron) is a subatomic particle of matter. It holds a negative charge, equals in module to the one of a positron. It is classified as fermion. It is represented as:

$$(120,80) \text{ i1 o11 fermion,label=} e^- \text{i1,o1}$$

Figure 1: Representation of an Electron.

0.1.2 Positron

A positron e^+ (Figure fig:positron), an anti-electron, is a subatomic particle of anti-matter. It holds a positive charge, equals in module to the one of an electron. It is classified as fermion. Note that a positron looks as an electron that travels back in time, according to the mathematics of QED. It is represented as:

$$(120,80) \text{ i1 o1 fermion,label=} e^+ \text{o1,i1}$$

Figure 2: Representation of a Positron.

0.1.3 Photon

A photon γ (Figure fig:photon) is a subatomic particle representing a discrete packet of energy. It can produce a couple positron-electron and be produced by the annihilation of a couple of positron-electron. It can be transmitted by scattering between two particles. As the absence of arrows implies, to a photon the time direction is not important.

$$(120,80) \text{ i1 o1 photon,label=} \gamma \text{i1,o1}$$

Figure 3: Representation of a Photon.

0.1.4 Vertex

A vertex v (Figure fig:vertex) is a point where three particles meet. In QED, only a vertex is allowed, one where a Positron e^+, an Electron e^- and a Photon γ meet. By rotating a vertex, its representation change. It can represent 6 different interactions.

(120,80) i1,i2 o1 fermion,label=e^-i1,v1 fermion,label=e^+v1,i2 photon,label=γv1,o1 vv1

Figure 4: A vertex of a Feynman diagram.

(120,80) i1,i2 o1 fermion,label=e^-i1,v1 photon,label=γv1,i2 fermion,label=e^-v1,o1 vv1

Figure 5: Electron absorbs a photon.

(120,80) i1,i2 o1 photon,label=γi1,v1 fermion,label=e^+v1,i2 fermion,label=e^+o1,v1 vv1

Figure 6: Positron absorbs photon.
1

(120,80) i1 o1,o2 photon,label=γo1,v1 fermion,label=e^-v1,o2 fermion,label=e^-i1,v1 vv1

Figure 7: Electron emits a photon.

(120,80) i1 o1,o2 photon,label=γo1,v1 fermion,label=e^+o2,v1 fermion,label=e^+v1,i1 vv1

Figure 8: Positron emits a photon.

(120,80) i1 o1,o2 fermion,label=e^+o1,v1 fermion,label=e^-v1,o2 photon,label=γi1,v1 vv1

(120,80) i1,i2 o1 fermion,label=e^-i1,v1 fermion,label=e^+v1,i2 photon,label=γv1,o1 vv1

Figure 9: Photon produces an electron - positron pair. Figure 10: Fermions annihilate and produce a photon.

0.2 First question

Draw the two-vertex diagrams for Bhabha scattering showing a single virtual photon interaction and describe what's happening at these vertices.

0.2.1 Answer

With time on the abscissas and space on the ordinates, we have the following two diagrams:

first-question

(120,80) i1,i2 o1,o2 fermion,label=e^-i1,v1,o1 fermion,label=e^+o2,v2,i2 photon,label=γv1,v2 v_1v1 v_2v2

Figure 11: Electron-Positron scattering.

Figure fig:scattering denotes an electron-positron scattering by emission of a virtual photon. We can choose to view the graph either as the positron emitting the virtual photon in v_2 and the electron absorbing it in v_1 or vice versa, with no more correct interpretation.

(120,80) i1,i2 o1,o2 fermion,label=e^-i1,v1 fermion,label=e^+v1,i2 fermion,label=e^+o2,v2 fermion,label=e^-v2,o1 photon,label=γv1,v2 v_1v1 v_2v2

Figure 12: Electron-Positron annihilation.

Figure fig:annihilation denotes an electron-positron annihilation by emission of a virtual photon. A couple positron-electron annihilates in v_1 and emits a virtual photon, that then produces a pair positron-electron in v_2.

The two graphs have the same on-shell particles, while the difference is found in what the virtual particles, in this case a single photon, does. Considering that by definition, the virtual particles mathematically speaking travel each and every possible path, the two graphs can be considered in this sense the same one.

0.3 Second question

Draw all possible four-vertex diagrams, ignoring self-energy diagrams (when a particle emits and then re-absorbs a virtual particle or a cople of virtual particles).

0.3.1 Answer

With time on the abscissas and space on the ordinates, we have the following diagrams:

second-question

(120,80) i1,i2 o1,o2 fermion,label=e^-i1,v2 fermion,label=e^-i2,v1 fermion,label=e^-v2,v3 fermion,label=e^-v3,o1 fermion,label=e^-v1,v4 fermion,label=e^-v4,o2 photon,label=γv1,v2 photon,label=γv3,v4

Figure 13: Electrons exchange photons.

(120,80) i1,i2 o1,o2 fermion,label=e^+v2,i1 fermion,label=e^+v1,i2 fermion,label=e^+v3,v2 fermion,label=e^+o1,v3 fermion,label=e^+v4,v1 fermion,label=e^+o2,v4 photon,label=γv2,v1 photon,label=γv4,v3

Figure 14: Positrons exchange photons.

The graphs in figures fig:ep and fig:pp are the same, only with reversed time.

(120,80) i1,i2 o1,o2 fermion,label=e^+v2,i1 fermion,label=e^-i2,v1 fermion,label=e^+v3,v2 fermion,label=e^+o1,v3 fermion,label=e^-v1,v4 fermion,label=e^-v4,o2 photon,label=γv1,v2 photon,label=γv3,v4

Figure 15: Electron and Positron exchange photons.

(120,80) i1,i2 o1,o2 fermion,label=e^-i1,v2 photon,label=γ_1i2,v1 photon,label=γ_1v3,v2 fermion,label=e^-v3,o1 fermion,label=e^-v1,v4 photon,label=γv4,o2 fermion,label=e^+v2,v1 fermion,label=e^+v4,v3 v_1v1 v_2v2 v_3v3 v_4v4

Figure 16: One of the possible interpretation is: a photon γ produces a virtual couple e^-, e^+ in v_1, then in v_2 an electron annihilates with the positron from v_1, producing a virtual photon γ_1. γ_1 then produces a couple e^-, e^+ in v_3 and in v_4 the previously produced fermions annihilates and produce a photon.

(120,80) i1,i2 o1,o2 fermion,label=e^+v2,i1 photon,label=γi2,v1 photon,label=γv3,v2 fermion,label=e^+o1,v3 fermion,label=e^+v4,v1 photon,label=γo2,v4 fermion,label=e^-v1,v2 fermion,label=e^-v3,v4 v_1v1 v_2v2 v_3v3 v_4v4

Figure 17: One of the possible interpretation is: a photon γ produces a virtual couple e^-, e^+ in v_1, then in v_2 a positron annihilates with the electron from v_2, producing a virtual photon γ_1. γ_1 then produces a couple e^-, e^+ in v_3 and in v_4 the previously produced fermions annihilates and produce a photon.

The graphs in figures fig:ep4 and fig:pp4 are the same, only with reversed time.