

1 Exercise: Histograms

C++ macro:

```
1 #include "TCanvas.h"
2 #include "TR00T.h"
3 #include "TGraphErrors.h"
4 #include "TF1.h"
5 #include "TH1F.h"
6 #include "TLegend.h"
7 #include "TFile.h"
8 #include "TArrow.h"
9 #include "TLatex.h"
10 #include "TMath.h"
11 #include "TMultiGraph.h"
12
13 #include <iostream>
14 #include <math.h>
15 #include <vector>
16 #include <stdlib.h>
17 #include <string>
18
19 using namespace std;
20
21 class Histogram
22 {
23     protected:
24         vector<double> x1, x;
25         //Histogram with 10 bins ranging from 0 to 100
26         TH1F *h1 = new TH1F("h1", "Histogram; x; Events", 10, 0, 100);
27         TGraph *g1 = new TGraph();
28     public:
29         Histogram () {};
```

```
30
31     void FillHistogram()
32     {
33         //Fill the histogram with three differents numbers
34         x1.push_back(11.3); x1.push_back(25.4); x1.push_back(18.1);
35
36         for (unsigned int i = 0; i < x1.size(); ++i)
37         {
38             h1 -> Fill(x1.at(i));
39         }
40
41         //Fill the histogram with the square and square-root of all integers
42         from 0 to 9
43         x1.clear();
44
45         for (unsigned int i = 0; i <= 9; ++i)
46         {
47             x1.push_back(pow(i, 2));
48             h1 -> Fill(x1.at(i));
49         }
50
51         x1.clear();
```

```

52     for (unsigned int i = 0; i <= 9; ++i)
53     {
54         x1.push_back(TMath::Sqrt(i));
55         h1 -> Fill(x1.at(i));
56     }
57
58     //Draw the histogram
59     TCanvas *c1 = new TCanvas("c1", "c1", 1024, 800);
60     h1 -> Draw();
61
62     //Derivative quadratic function
63     x1.clear();
64
65     TF1 f1("func1","pow(x, 2)", 0, 10);
66
67     for (unsigned int i = 0; i <= 9; ++i)
68     {
69         x.push_back(i);
70         x1.push_back(f1.Derivative(x.at(i))); //derivative quadratic
function
71         g1 -> SetPoint(i, x.at(i), x1.at(i));
72     }
73
74     g1 -> Draw("same*1");
75     c1 -> Print("histogram_C.png");
76
77     //Mean value and rms of the derivative of the quadratic function
78     //Mean value:
79     unsigned int counter1 = 0;
80
81     for (unsigned int i = 0; i < x1.size(); ++i)
82     {
83         counter1 += x1.at(i);
84     }
85
86     cout << "Mean derivative square function: " << counter1/x1.size() <<
endl;
87
88     //RMS:
89     unsigned int counter2 = 0;
90
91     for (unsigned int i = 0; i < x1.size(); ++i)
92     {
93         counter2 += pow(x1.at(i), 2);
94     }
95
96     cout << "RMS derivative square function: " << TMath::Sqrt(counter2/x1.
size()) << endl;
97
98     double error;
99     double integral = h1 -> IntegralAndError(0, 100, error, "");
100    cout << "Histogram integral +- error = " << integral << " +- " << error
<< endl;
101
102    //Identify the bin with the maxmun number of entries
103    for (unsigned int i = 1; i <= 10; ++i)

```

```

104         {
105             cout << "Bin number: " << i << " Number of entries: " << h1 ->
GetBinContent(i) << endl;
106         }
107     }
108
109     virtual ~Histogram () {};
110 };
111
112
113 void ExerciseHist()
114 {
115     Histogram *obj1 = new Histogram();
116     obj1 -> FillHistogram();
117 }

```

Python macro:

```

1 import ROOT
2 import numpy as np
3
4 class Histogram:
5     def __init__(self, data1, data2):
6         hist = ROOT.TH1F("variable", "Histogram; x; events", 10, 0, 100)
7         g1 = ROOT.TGraph()
8
9         for i in range(data1.size):
10             hist.Fill(data1[i])
11
12         for i in range(data2.size):
13             g1.SetPoint(i, i, data2[i])
14
15         print('Histogram integral: ' + str(hist.Integral()))
16
17         for i in range(1, 11):
18             print("Bin number: " + str(i) + ' Number of entries: ' + str(hist.
GetBinContent(i)))
19
20         c1 = ROOT.TCanvas("c1", "c1", 1024, 800)
21         hist.Draw()
22         g1.Draw("same*1")
23         c1.Print("histogram_python_ROOT.png")
24
25 class MeanAndRMS:
26     def __init__(self, data):
27         counter1 = 0
28         for i in range(0, data.size):
29             counter1 += data[i]
30         mean = counter1/data.size
31         print('Mean derivative square function: ' + str(mean))
32
33         counter2 = 0
34         for i in range(0, data.size):
35             counter2 += data[i]**2
36         RMS = np.sqrt(counter2/data.size)
37         print('RMS derivative square function: ' + str(RMS))
38

```

```

39 data_list_1 = [11.3, 25.4, 18.1]
40 data_list_2 = []
41
42 for i in range(0, 10):
43     data_list_1.append(i**2)
44     data_list_1.append(np.sqrt(i))
45
46 f1 = ROOT.TF1("func1","x**2", 0, 10)
47
48 for i in range(0, 10):
49     data_list_2.append(f1.Derivative(i))
50
51 data_np_array_1 = np.array(data_list_1)
52 data_np_array_2 = np.array(data_list_2)
53
54 obj1 = Histogram(data_np_array_1, data_np_array_2)
55 obj2 = MeanAndRMS(data_np_array_2)

```

Output C++ macro:

```

1 -----
2 | Welcome to ROOT 6.10/06                               http://root.cern.ch |
3 |                                                         (c) 1995-2017, The ROOT Team |
4 | Built for linuxx8664gcc                               |
5 | From tag v6-10-06, 19 September 2017                  |
6 | Try '.help', '.demo', '.license', '.credits', '.quit'/''.q' |
7 -----
8
9
10 Processing ExerciseHist.C...
11 Mean derivative square function: 8
12 RMS derivative square function: 10.6301
13 Histogram integral +- error = 23 +- 4.79583
14 Bin number: 1 Number of entries: 14
15 Bin number: 2 Number of entries: 3
16 Bin number: 3 Number of entries: 2
17 Bin number: 4 Number of entries: 1
18 Bin number: 5 Number of entries: 1
19 Bin number: 6 Number of entries: 0
20 Bin number: 7 Number of entries: 1
21 Bin number: 8 Number of entries: 0
22 Bin number: 9 Number of entries: 1
23 Bin number: 10 Number of entries: 0

```

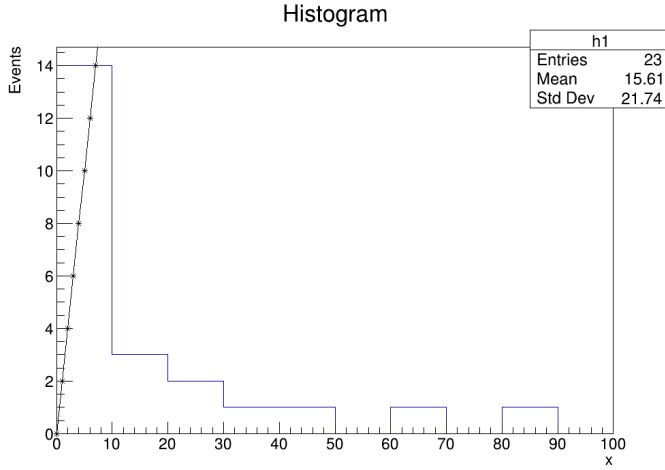
Output Python macro:

```

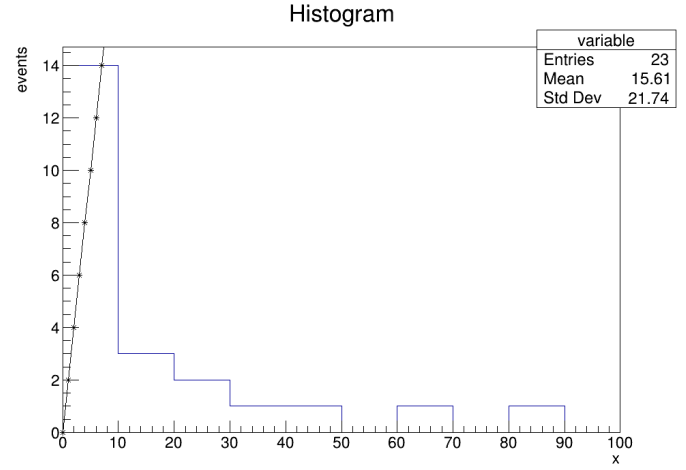
1 Histogram integral: 23.0
2 Bin number: 1 Number of entries: 14.0
3 Bin number: 2 Number of entries: 3.0
4 Bin number: 3 Number of entries: 2.0
5 Bin number: 4 Number of entries: 1.0
6 Bin number: 5 Number of entries: 1.0
7 Bin number: 6 Number of entries: 0.0
8 Bin number: 7 Number of entries: 1.0
9 Bin number: 8 Number of entries: 0.0
10 Bin number: 9 Number of entries: 1.0
11 Bin number: 10 Number of entries: 0.0
12 Mean derivative square function: 9.0

```

13 RMS derivative square function: 10.677078252



(a) Output histogram of the C++ code.



(b) Output histogram of the Python code.

2 $e^- + e^+ \rightarrow \mu^- + \mu^+$ Process

2.1 Generating the process

Output:

```

1 *****
2 *
3 *           W E L C O M E to
4 *       M A D G R A P H 5 _ a M C @ N L O
5 *
6 *
7 *           *           *
8 *         *       * *       *
9 *       * * * * 5 * * * *
10 *      *       * *       *
11 *     *           *
12 *
13 *   VERSION 3.1.0           2021-03-30
14 *
15 *   The MadGraph5_aMC@NLO Development Team - Find us at
16 *   https://server06.fynu.ucl.ac.be/projects/madgraph
17 *   and
18 *   http://amcatnlo.web.cern.ch/amcatnlo/
19 *
20 *   Type 'help' for in-line help.
21 *   Type 'tutorial' to learn how MG5 works
22 *   Type 'tutorial aMCatNLO' to learn how aMC@NLO works
23 *   Type 'tutorial MadLoop' to learn how MadLoop works
24 *
25 *****
26 load MG5 configuration from ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/input/
   mg5_configuration.txt

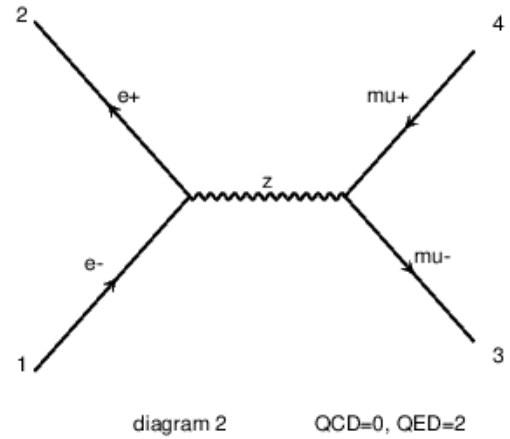
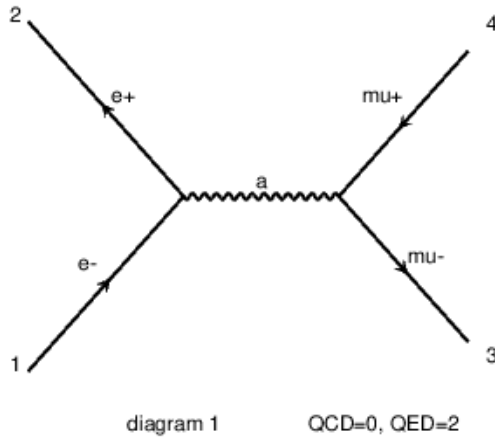
```

```

27 fastjet-config does not seem to correspond to a valid fastjet-config executable (v3
   +). We will use fjcore instead.
28 Please set the 'fastjet' variable to the full (absolute) /PATH/T0/fastjet-config (
   including fastjet-config).
29 MG5_aMC> set fastjet /PATH/T0/fastjet-config
30
31 set lhpdf to lhpdf-config
32 /user/e/edson/public/exp_phys/MG5_aMC_v3_1_0/HEPTools/lhpdf6_py3/bin/lhpdf-config
   does not seem to correspond to a valid lhpdf-config executable.
33 Please set the 'lhpdf' variable to the (absolute) /PATH/T0/lhpdf-config (
   including lhpdf-config).
34 Note that you can still compile and run aMC@NLO with the built-in PDFs
35 MG5_aMC> set lhpdf /PATH/T0/lhpdf-config
36
37 Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
38 Using default eps viewer "gv". Set another one in ./input/mg5_configuration.txt
39 No valid web browser found. Please set in ./input/mg5_configuration.txt
40 import /user/e/exphys02/TareaIIFisicaExp/Problema2/Item21/run.dat
41 The import format was not given, so we guess it as command
42
43
44 generate e- e+ > mu- mu+
45 No model currently active, so we import the Standard Model
46 INFO: Restrict model sm with file ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/
   models/sm/restrict_default.dat .
47 INFO: Run "set stdout_level DEBUG" before import for more information.
48 INFO: Change particles name to pass to MG5 convention
49 Defined multiparticle p = g u c d s u~ c~ d~ s~
50 Defined multiparticle j = g u c d s u~ c~ d~ s~
51 Defined multiparticle l+ = e+ mu+
52 Defined multiparticle l- = e- mu-
53 Defined multiparticle vl = ve vm vt
54 Defined multiparticle vl~ = ve~ vm~ vt~
55 Defined multiparticle all = g u c d s u~ c~ d~ s~ a ve vm vt e- mu- ve~ vm~ vt~ e+
   mu+ t b t~ b~ z w+ h w- ta- ta+
56 INFO: Checking for minimal orders which gives processes.
57 INFO: Please specify coupling orders to bypass this step.
58 INFO: Trying process: e- e+ > mu- mu+ WEIGHTED<=4 @1
59 INFO: Process has 2 diagrams
60 1 processes with 2 diagrams generated in 0.006 s
61 Total: 1 processes with 2 diagrams
62
63
64 display processes
65 Process: e- e+ > mu- mu+ WEIGHTED<=4 @1
66
67
68 display diagrams
69 Drawing Process: e- e+ > mu- mu+ WEIGHTED<=4 @1
70 Wrote file /tmp/diagrams_1_emep_mummup.eps
71 open /tmp/diagrams_1_emep_mummup.eps
72 time to draw 0.004775524139404297
73 quit

```

Feynman diagrams:



2.2 Exporting the process

Output:

```

1 *****
2 *
3 *           W E L C O M E to
4 *       M A D G R A P H 5 _ a M C @ N L O
5 *
6 *
7 *           *
8 *       *           *
9 *   * * * * 5 * * * *
10 *       *           *
11 *           *
12 *
13 *   VERSION 3.1.0
14 *
15 *   The MadGraph5_aMC@NLO Development Team - Find us at
16 *   https://server06.fynu.ucl.ac.be/projects/madgraph
17 *   and
18 *   http://amcatnlo.web.cern.ch/amcatnlo/
19 *
20 *   Type 'help' for in-line help.
21 *   Type 'tutorial' to learn how MG5 works
22 *   Type 'tutorial aMCatNLO' to learn how aMC@NLO works
23 *   Type 'tutorial MadLoop' to learn how MadLoop works
24 *
25 *****
26 load MG5 configuration from ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/input/
   mg5_configuration.txt
27 fastjet-config does not seem to correspond to a valid fastjet-config executable (v3
   +). We will use fjcore instead.
28 Please set the 'fastjet' variable to the full (absolute) /PATH/T0/fastjet-config (
   including fastjet-config).

```

```

29 MG5_aMC> set fastjet /PATH/T0/fastjet-config
30
31 set lhpdf to lhpdf-config
32 /user/e/edson/public/exp_phys/MG5_aMC_v3_1_0/HEPTools/lhpdf6_py3/bin/lhpdf-config
   does not seem to correspond to a valid lhpdf-config executable.
33 Please set the 'lhpdf' variable to the (absolute) /PATH/T0/lhpdf-config (
   including lhpdf-config).
34 Note that you can still compile and run aMC@NLO with the built-in PDFs
35 MG5_aMC> set lhpdf /PATH/T0/lhpdf-config
36
37 Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
38 Using default eps viewer "gv". Set another one in ./input/mg5_configuration.txt
39 No valid web browser found. Please set in ./input/mg5_configuration.txt
40 import /user/e/exphys02/TareaIIFisicaExp/Problema2/Item22/run.dat
41 The import format was not given, so we guess it as command
42
43
44 generate e- e+ > mu- mu+
45 No model currently active, so we import the Standard Model
46 INFO: Restrict model sm with file ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/
   models/sm/restrict_default.dat .
47 INFO: Run "set stdout_level DEBUG" before import for more information.
48 INFO: Change particles name to pass to MG5 convention
49 Defined multiparticle p = g u c d s u~ c~ d~ s~
50 Defined multiparticle j = g u c d s u~ c~ d~ s~
51 Defined multiparticle l+ = e+ mu+
52 Defined multiparticle l- = e- mu-
53 Defined multiparticle vl = ve vm vt
54 Defined multiparticle vl~ = ve~ vm~ vt~
55 Defined multiparticle all = g u c d s u~ c~ d~ s~ a ve vm vt e- mu- ve~ vm~ vt~ e+
   mu+ t b t~ b~ z w+ h w- ta- ta+
56 INFO: Checking for minimal orders which gives processes.
57 INFO: Please specify coupling orders to bypass this step.
58 INFO: Trying process: e- e+ > mu- mu+ WEIGHTED<=4 @1
59 INFO: Process has 2 diagrams
60 1 processes with 2 diagrams generated in 0.006 s
61 Total: 1 processes with 2 diagrams
62
63
64 output MYFIRSTPROCESS
65 INFO: initialize a new directory: MYFIRSTPROCESS
66 INFO: remove old information in MYFIRSTPROCESS
67 INFO: Organizing processes into subprocess groups
68 INFO: Generating Helas calls for process: e- e+ > mu- mu+ WEIGHTED<=4 @1
69 INFO: Processing color information for process: e- e+ > mu- mu+ @1
70 INFO: Creating files in directory P1_ll_ll
71 INFO: Generating Feynman diagrams for Process: e- e+ > mu- mu+ WEIGHTED<=4 @1
72 INFO: Finding symmetric diagrams for subprocess group ll_ll
73 Generated helas calls for 1 subprocesses (2 diagrams) in 0.004 s
74 Wrote files for 8 helas calls in 0.994 s
75 ALOHA: aloha starts to compute helicity amplitudes
76 ALOHA: aloha creates 3 routines in 4.011 s
77 save configuration file to /user/e/exphys02/TareaIIFisicaExp/Problema2/Item22/
   MYFIRSTPROCESS/Cards/me5_configuration.txt
78 INFO: Use Fortran compiler gfortran
79 INFO: Use c++ compiler g++

```



```

80 INFO: Generate jpeg diagrams
81 INFO: Generate web pages
82 Output to directory /user/e/exphys02/TareaIIFisicaExp/Problema2/Item22/
   MYFIRSTPROCESS done.
83 Type "launch" to generate events from this process, or see
84 /user/e/exphys02/TareaIIFisicaExp/Problema2/Item22/MYFIRSTPROCESS/README
85 Run "open index.html" to see more information about this process.
86 quit

```

2.3 Launching the process

Output:

```

1 *****
2 *
3 *           W E L C O M E to           *
4 *       M A D G R A P H 5 _ a M C @ N L O   *
5 *                                           *
6 *                                           *
7 *           *               *           *
8 *           *       * *       *           *
9 *           * * * * 5 * * * *           *
10 *           *       * *       *           *
11 *           *               *           *
12 *                                           *
13 *       VERSION 3.1.0               2021-03-30   *
14 *                                           *
15 *       The MadGraph5_aMC@NLO Development Team - Find us at   *
16 *       https://server06.fynu.ucl.ac.be/projects/madgraph     *
17 *                   and                                         *
18 *       http://amcatnlo.web.cern.ch/amcatnlo/                 *
19 *                                           *
20 *           Type 'help' for in-line help.           *
21 *           Type 'tutorial' to learn how MG5 works         *
22 *           Type 'tutorial aMCatNLO' to learn how aMC@NLO works *
23 *           Type 'tutorial MadLoop' to learn how MadLoop works *
24 *                                           *
25 *****
26 load MG5 configuration from ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/input/
   mg5_configuration.txt
27 fastjet-config does not seem to correspond to a valid fastjet-config executable (v3
   +). We will use fjcore instead.
28 Please set the 'fastjet' variable to the full (absolute) /PATH/T0/fastjet-config (
   including fastjet-config).
29 MG5_aMC> set fastjet /PATH/T0/fastjet-config
30
31 set lhpdf to lhpdf-config
32 /user/e/edson/public/exp_phys/MG5_aMC_v3_1_0/HEPTools/lhpdf6_py3/bin/lhpdf-config
   does not seem to correspond to a valid lhpdf-config executable.
33 Please set the 'lhpdf' variable to the (absolute) /PATH/T0/lhpdf-config (
   including lhpdf-config).
34 Note that you can still compile and run aMC@NLO with the built-in PDFs
35 MG5_aMC> set lhpdf /PATH/T0/lhpdf-config
36
37 Using default text editor "vi". Set another one in ./input/mg5_configuration.txt

```

```

38 Using default eps viewer "gv". Set another one in ./input/mg5_configuration.txt
39 No valid web browser found. Please set in ./input/mg5_configuration.txt
40 import /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/run.dat
41 The import format was not given, so we guess it as command
42
43
44 generate e- e+ > mu- mu+
45 No model currently active, so we import the Standard Model
46 INFO: Restrict model sm with file ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/
    models/sm/restrict_default.dat .
47 INFO: Run "set stdout_level DEBUG" before import for more information.
48 INFO: Change particles name to pass to MG5 convention
49 Defined multiparticle p = g u c d s u~ c~ d~ s~
50 Defined multiparticle j = g u c d s u~ c~ d~ s~
51 Defined multiparticle l+ = e+ mu+
52 Defined multiparticle l- = e- mu-
53 Defined multiparticle vl = ve vm vt
54 Defined multiparticle vl~ = ve~ vm~ vt~
55 Defined multiparticle all = g u c d s u~ c~ d~ s~ a ve vm vt e- mu- ve~ vm~ vt~ e+
    mu+ t b t~ b~ z w+ h w- ta- ta+
56 INFO: Checking for minimal orders which gives processes.
57 INFO: Please specify coupling orders to bypass this step.
58 INFO: Trying process: e- e+ > mu- mu+ WEIGHTED<=4 @1
59 INFO: Process has 2 diagrams
60 1 processes with 2 diagrams generated in 0.006 s
61 Total: 1 processes with 2 diagrams
62
63
64 output MYFIRSTPROCESS
65 INFO: initialize a new directory: MYFIRSTPROCESS
66 INFO: remove old information in MYFIRSTPROCESS
67 INFO: Organizing processes into subprocess groups
68 INFO: Generating Helas calls for process: e- e+ > mu- mu+ WEIGHTED<=4 @1
69 INFO: Processing color information for process: e- e+ > mu- mu+ @1
70 INFO: Creating files in directory P1_ll_ll
71 INFO: Generating Feynman diagrams for Process: e- e+ > mu- mu+ WEIGHTED<=4 @1
72 INFO: Finding symmetric diagrams for subprocess group ll_ll
73 Generated helas calls for 1 subprocesses (2 diagrams) in 0.010 s
74 Wrote files for 8 helas calls in 1.436 s
75 ALOHA: aloha starts to compute helicity amplitudes
76 ALOHA: aloha creates 3 routines in 3.361 s
77 save configuration file to /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/
    MYFIRSTPROCESS/Cards/me5_configuration.txt
78 INFO: Use Fortran compiler gfortran
79 INFO: Use c++ compiler g++
80 INFO: Generate jpeg diagrams
81 INFO: Generate web pages
82 Output to directory /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/
    MYFIRSTPROCESS done.
83 Type "launch" to generate events from this process, or see
84 /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/MYFIRSTPROCESS/README
85 Run "open index.html" to see more information about this process.
86
87
88 launch MYFIRSTPROCESS
89 *****

```

```

90 *
91 *           W E L C O M E to
92 *       M A D G R A P H 5 _ a M C @ N L O
93 *           M A D E V E N T
94 *
95 *           *               *
96 *           *       * *       *
97 *           * * * * 5 * * * *
98 *           *       * *       *
99 *           *               *
100 *
101 *       VERSION 3.1.0               2021-03-30
102 *
103 *       The MadGraph5_aMC@NLO Development Team - Find us at
104 *       https://server06.fynu.ucl.ac.be/projects/madgraph
105 *
106 *       Type 'help' for in-line help.
107 *
108 *****
109 INFO: load configuration from /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/
110 MYFIRSTPROCESS/Cards/me5_configuration.txt
111 INFO: load configuration from /user/e/edson/public/exp_phys/MG5_aMC_v3_1_0/input/
112 mg5_configuration.txt
113 INFO: load configuration from /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/
114 MYFIRSTPROCESS/Cards/me5_configuration.txt
115 Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
116 No valid web browser found. Please set in ./input/mg5_configuration.txt
117 generate_events run_01
118 The following switches determine which programs are run:
119 /===== Description =====|===== values
120 =====|===== other options =====\
121 | 1. Choose the shower/hadronization program | shower =
122 | OFF | Pythia8 |
123 | 2. Choose the detector simulation program | detector =
124 | OFF | Delphes |
125 | 3. Choose an analysis package (plot/convert) | analysis =
126 | ExRoot | OFF |
127 | 4. Decay onshell particles | madspin =
128 | OFF | ON|onshell|full |
129 | 5. Add weights to events for new hypp. | reweight =
130 | OFF | ON |
131 \=====
132
133 Either type the switch number (1 to 5) to change its setting,
134 Set any switch explicitly (e.g. type 'shower=Pythia8' at the prompt)
135 Type 'help' for the list of all valid option
136 Type '0', 'auto', 'done' or just press enter when you are done.
137 The answer to the previous question is not set in your input file
138 Use 0 value
139 Do you want to edit a card (press enter to bypass editing)?
140 /-----\
141 | param : param_card.dat
142 |
143 | run : run_card.dat
144 |
145 \-----/

```

```

134 you can also
135 - enter the path to a valid card or banner.
136 - use the 'set' command to modify a parameter directly.
137 The set option works only for param_card and run_card.
138 Type 'help set' for more information on this command.
139 - call an external program (ASperGE/MadWidth/...).
140 Type 'help' for the list of available command
141 0, done, 1, param, 2, run, enter path
142 The answer to the previous question is not set in your input file
143 Use 0 value
144 INFO: Update the dependent parameter of the param_card.dat
145 Generating 10000 events with run name run_01
146 survey run_01
147 INFO: compile directory
148 Not able to open file /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/
MYFIRSTPROCESS/crossx.html since no program configured. Please set one in ./
input/mg5_configuration.txt
149 compile Source Directory
150 Using random number seed offset = 21
151 INFO: Running Survey
152 Creating Jobs
153 Working on SubProcesses
154 INFO: Compiling for process 1/1.
155 INFO: P1_ll_ll
156 INFO: P1_ll_ll
157 INFO: Idle: 1, Running: 0, Completed: 0 [ current time: 22h06 ]
158 INFO: Idle: 0, Running: 0, Completed: 1 [ 1.5s ]
159 INFO: Idle: 0, Running: 0, Completed: 1 [ 1.5s ]
160 INFO: End survey
161 refine 10000
162 Creating Jobs
163 INFO: Refine results to 10000
164 INFO: Generating 10000.0 unweighted events.
165 sum of cpu time of last step: 0 second
166 INFO: Effective Luminosity 115063.76450282866 pb-1
167 INFO: need to improve 2 channels
168 - Current estimate of cross-section: 0.10429 +- 0.0003023733999544272
169 P1_ll_ll
170 INFO: Idle: 1, Running: 12, Completed: 0 [ current time: 22h06 ]
171 INFO: Idle: 0, Running: 12, Completed: 1 [ 1.2s ]
172 INFO: Idle: 0, Running: 0, Completed: 13 [ 2.2s ]
173 INFO: Combining runs
174 sum of cpu time of last step: 8 seconds
175 INFO: finish refine
176 refine 10000 --treshold=0.9
177 No need for second refine due to stability of cross-section
178 INFO: Combining Events
179 == Results Summary for run: run_01 tag: tag_1 ==
180
181 Cross-section : 0.1042 +- 7.702e-05 pb
182 Nb of events : 10000
183
184 store_events
185 INFO: Storing parton level results
186 INFO: End Parton
187 reweight -from_cards

```

```

188 decay_events -from_cards
189 INFO: Creating root files
190 ** Reading /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/MYFIRSTPROCESS/Events
    /run_01/unweighted_events.lhe
191 ** Exiting...
192 INFO: storing files of previous run
193 INFO: Done
194 quit
195 INFO:
196 more information in /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/
    MYFIRSTPROCESS/index.html
197 quit

```

2.4 The CM energy collision

Output:

```

1 *****
2 *
3 *           W E L C O M E to
4 *       M A D G R A P H 5 _ a M C @ N L O
5 *
6 *
7 *           *           *
8 *       *           * *           *
9 *           * * * * 5 * * * *
10 *       *           * *           *
11 *           *           *
12 *
13 *       VERSION 3.1.0           2021-03-30
14 *
15 *       The MadGraph5_aMC@NLO Development Team - Find us at
16 *       https://server06.fynu.ucl.ac.be/projects/madgraph
17 *           and
18 *       http://amcatnlo.web.cern.ch/amcatnlo/
19 *
20 *       Type 'help' for in-line help.
21 *       Type 'tutorial' to learn how MG5 works
22 *       Type 'tutorial aMCatNLO' to learn how aMC@NLO works
23 *       Type 'tutorial MadLoop' to learn how MadLoop works
24 *
25 *****
26 load MG5 configuration from ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/input/
    mg5_configuration.txt
27 fastjet-config does not seem to correspond to a valid fastjet-config executable (v3
    +). We will use fjcore instead.
28 Please set the 'fastjet' variable to the full (absolute) /PATH/T0/fastjet-config (
    including fastjet-config).
29 MG5_aMC> set fastjet /PATH/T0/fastjet-config
30
31 set lhpdf to lhpdf-config
32 /user/e/edson/public/exp_phys/MG5_aMC_v3_1_0/HEPTools/lhpdf6_py3/bin/lhpdf-config
    does not seem to correspond to a valid lhpdf-config executable.
33 Please set the 'lhpdf' variable to the (absolute) /PATH/T0/lhpdf-config (
    including lhpdf-config).

```

```

34 Note that you can still compile and run aMC@NLO with the built-in PDFs
35 MG5_aMC> set lhpdf /PATH/TO/lhapdf-config
36
37 Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
38 Using default eps viewer "gv". Set another one in ./input/mg5_configuration.txt
39 No valid web browser found. Please set in ./input/mg5_configuration.txt
40 import /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/run.dat
41 The import format was not given, so we guess it as command
42
43
44 generate e- e+ > mu- mu+
45 No model currently active, so we import the Standard Model
46 INFO: Restrict model sm with file ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/
    models/sm/restrict_default.dat .
47 INFO: Run "set stdout_level DEBUG" before import for more information.
48 INFO: Change particles name to pass to MG5 convention
49 Defined multiparticle p = g u c d s u~ c~ d~ s~
50 Defined multiparticle j = g u c d s u~ c~ d~ s~
51 Defined multiparticle l+ = e+ mu+
52 Defined multiparticle l- = e- mu-
53 Defined multiparticle vl = ve vm vt
54 Defined multiparticle vl~ = ve~ vm~ vt~
55 Defined multiparticle all = g u c d s u~ c~ d~ s~ a ve vm vt e- mu- ve~ vm~ vt~ e+
    mu+ t b t~ b~ z w+ h w- ta- ta+
56 INFO: Checking for minimal orders which gives processes.
57 INFO: Please specify coupling orders to bypass this step.
58 INFO: Trying process: e- e+ > mu- mu+ WEIGHTED<=4 @1
59 INFO: Process has 2 diagrams
60 1 processes with 2 diagrams generated in 0.006 s
61 Total: 1 processes with 2 diagrams
62
63
64 output MYFIRSTPROCESS
65 INFO: initialize a new directory: MYFIRSTPROCESS
66 INFO: remove old information in MYFIRSTPROCESS
67 INFO: Organizing processes into subprocess groups
68 INFO: Generating Helas calls for process: e- e+ > mu- mu+ WEIGHTED<=4 @1
69 INFO: Processing color information for process: e- e+ > mu- mu+ @1
70 INFO: Creating files in directory P1_ll_ll
71 INFO: Generating Feynman diagrams for Process: e- e+ > mu- mu+ WEIGHTED<=4 @1
72 INFO: Finding symmetric diagrams for subprocess group ll_ll
73 Generated helas calls for 1 subprocesses (2 diagrams) in 0.012 s
74 Wrote files for 8 helas calls in 1.568 s
75 ALOHA: aloha starts to compute helicity amplitudes
76 ALOHA: aloha creates 3 routines in 2.962 s
77 save configuration file to /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/
    MYFIRSTPROCESS/Cards/me5_configuration.txt
78 INFO: Use Fortran compiler gfortran
79 INFO: Use c++ compiler g++
80 INFO: Generate jpeg diagrams
81 INFO: Generate web pages
82 Output to directory /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/
    MYFIRSTPROCESS done.
83 Type "launch" to generate events from this process, or see
84 /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/MYFIRSTPROCESS/README
85 Run "open index.html" to see more information about this process.

```

```

86
87
88 launch MYFIRSTPROCESS
89 *****
90 *
91 *           W E L C O M E to
92 *       M A D G R A P H 5 _ a M C @ N L O
93 *           M A D E V E N T
94 *
95 *           *           *
96 *       *           * *           *
97 *           * * * * 5 * * * *
98 *       *           * *           *
99 *           *           *
100 *
101 *       VERSION 3.1.0           2021-03-30
102 *
103 *       The MadGraph5_aMC@NLO Development Team - Find us at
104 *       https://server06.fynu.ucl.ac.be/projects/madgraph
105 *
106 *       Type 'help' for in-line help.
107 *
108 *****
109 INFO: load configuration from /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/
110 MYFIRSTPROCESS/Cards/me5_configuration.txt
111 INFO: load configuration from /user/e/edson/public/exp_phys/MG5_aMC_v3_1_0/input/
112 mg5_configuration.txt
113 INFO: load configuration from /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/
114 MYFIRSTPROCESS/Cards/me5_configuration.txt
115 Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
116 No valid web browser found. Please set in ./input/mg5_configuration.txt
117 generate_events run_01
118 set ebeam1 100
119 INFO: modify parameter ebeam1 of the run_card.dat to 100.0
120 set ebeam2 100
121 INFO: modify parameter ebeam2 of the run_card.dat to 100.0
122 INFO: Update the dependent parameter of the param_card.dat
123 Generating 10000 events with run name run_01
124 survey run_01
125 INFO: compile directory
126 Not able to open file /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/
127 MYFIRSTPROCESS/crossx.html since no program configured. Please set one in ./
128 input/mg5_configuration.txt
129 compile Source Directory
130 Using random number seed offset = 21
131 INFO: Running Survey
132 Creating Jobs
133 Working on SubProcesses
134 INFO: Compiling for process 1/1.
135 INFO: P1_ll_ll
136 INFO: P1_ll_ll
137 INFO: Idle: 1, Running: 0, Completed: 0 [ current time: 22h18 ]
138 INFO: Idle: 0, Running: 0, Completed: 1 [ 1.3s ]
139 INFO: Idle: 0, Running: 0, Completed: 1 [ 1.4s ]
140 INFO: End survey
141 refine 10000

```

```

137 Creating Jobs
138 INFO: Refine results to 10000
139 INFO: Generating 10000.0 unweighted events.
140 sum of cpu time of last step: 0 second
141 INFO: Effective Luminosity 4298.1482144775955 pb-1
142 INFO: need to improve 2 channels
143 - Current estimate of cross-section: 2.7919 +- 0.008363567345337754
144   P1_ll_ll
145 INFO: Idle: 1, Running: 12, Completed: 0 [ current time: 22h18 ]
146 INFO: Idle: 0, Running: 10, Completed: 3 [ 1s ]
147 INFO: Idle: 0, Running: 0, Completed: 13 [ 2.7s ]
148 INFO: Combining runs
149 sum of cpu time of last step: 9 seconds
150 INFO: finish refine
151 refine 10000 --treshold=0.9
152 No need for second refine due to stability of cross-section
153 INFO: Combining Events
154   == Results Summary for run: run_01 tag: tag_1 ==
155
156   Cross-section : 2.789 +- 0.002403 pb
157   Nb of events : 10000
158
159 store_events
160 INFO: Storing parton level results
161 INFO: End Parton
162 reweight -from_cards
163 decay_events -from_cards
164 INFO: Creating root files
165 ** Reading /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/MYFIRSTPROCESS/Events
   /run_01/unweighted_events.lhe
166 ** Exiting...
167 INFO: storing files of previous run
168 INFO: Done
169 quit
170 INFO:
171 more information in /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/
   MYFIRSTPROCESS/index.html
172 quit

```

3 Problem Madgrapgh

C++ macro:

```

1 #include "TCanvas.h"
2 #include "TROOT.h"
3 #include "TGraphErrors.h"
4 #include "TF1.h"
5 #include "TH1F.h"
6 #include "TLegend.h"
7 #include "TFile.h"
8 #include "TArrow.h"
9 #include "TLatex.h"
10 #include "TMath.h"
11 #include "TMultiGraph.h"
12

```



```

13 #include <iostream>
14 #include <math.h>
15 #include <vector>
16 #include <stdlib.h>
17 #include <string>
18
19 using namespace std;
20
21 class ReadingFileVariables
22 {
23     protected:
24         //file variables
25         ifstream inFile1;
26         string aux_string;
27         //items
28         double numbers_items;
29         //vectors to store elements
30         vector<double> numbers_vector;
31         //counters
32         int counter_numbers;
33     public:
34         ReadingFileVariables() {};
35         virtual ~ ReadingFileVariables() {};
36 };
37
38 class ReadingFile: public ReadingFileVariables
39 {
40     public:
41         ReadingFile () {};
42
43         void OpenFileOne(string aux_string)
44         {
45             inFile1.open(aux_string);
46         }
47
48         void CheckForErrorOne()
49         {
50             if(inFile1.fail())
51             {
52                 cerr << "Error opening the file :(" << endl; //Error message
53                 exit(1);
54             }
55         }
56
57         void ReadTheElementsOfTheFileNumbers()
58         {
59             counter_numbers = 0;
60
61             while (!inFile1.eof())
62             {
63                 inFile1 >> numbers_items;
64                 numbers_vector.push_back(numbers_items);
65                 ++counter_numbers;
66             }
67
68             cout << counter_numbers << " Number items found!" << endl;

```

```

69     }
70
71     void ShowTheElementsOfTheFileNumbers()
72     {
73         for (int i = 0; i < numbers_vector.size(); ++i)
74         {
75             cout << numbers_vector.at(i) << endl;
76         }
77     }
78
79     void CloseFileOne(){inFile1.close();}
80
81     ~ ReadingFile () {};}
82 };
83
84 class Plot: public ReadingFile
85 {
86     private:
87         vector<double> total_vector;
88         vector<double> cross_section_vector;
89         vector<double> CM_energy;
90     public:
91         Plot () {};}
92
93     void PlotCrossSection ()
94     {
95         for (unsigned int i = 0; i < numbers_vector.size(); ++i)
96         {
97             total_vector.push_back(numbers_vector.at(i));
98         }
99
100         for (unsigned int i = 0; i < total_vector.size()/2; ++i)
101         {
102             cross_section_vector.push_back(total_vector.at(i));
103         }
104
105         for (unsigned int i = total_vector.size()/2; i < total_vector.size() -
106 1; ++i)
107         {
108             CM_energy.push_back(total_vector.at(i));
109         }
110
111         TGraph *g1 = new TGraph(CM_energy.size(), &CM_energy[0], &
cross_section_vector[0]);
112         TCanvas *c1 = new TCanvas("c1", "c1", 1024, 800);
113
114         TF1 *f1 = new TF1("f1", "[2]*[1]*pow([0], 2)/( pow((x*x - pow([0], 2)),
115 2) + [1]/pow([0], 2) )", 90, 200);
116
117         f1 -> SetParameter(0, 90);
118         f1 -> SetParameter(2, 2.9*0.000001);
119         g1 -> SetLineColor(21);
120         g1 -> Fit("f1");
121         g1 -> Draw("AP");
122         g1 -> GetXaxis() -> SetTitle("#sqrt{s} [GeV]");

```

```

121 g1 -> GetYaxis() -> SetTitle("#sigma(e^{-} + e^{+} -> #mu^{-} + #mu
~^{+})");
122 g1 -> SetTitle("");
123
124 double *nx = g1 -> GetX();
125 double *ny = g1 -> GetY();
126
127 for (unsigned int j = 0; j < CM_energy.size(); ++j)
128 {
129     TMarker *m = new TMarker(nx[j], ny[j], 22);
130     m -> SetMarkerSize(2);
131     m -> SetMarkerColor(31 + j);
132     m -> Draw();
133 }
134
135 c1 -> Print("plot_problem_3.png");
136 }
137
138 ~ Plot () {};
139 };
140
141 void CrossSectionPlot()
142 {
143     Plot *File1 = new Plot();
144     string NameOfFile = "cross_section.txt"; //Name of our data set that is located
in our local storage drive
145
146     File1 -> OpenFileOne(NameOfFile);
147     File1 -> CheckForErrorOne();
148     File1 -> ReadTheElementsOfTheFileNumbers();
149     //File1 -> ShowTheElementsOfTheFileNumbers();
150     File1 -> CloseFileOne();
151     File1 -> PlotCrossSection();
152
153     return 0;
154 }

```

Output C++ macro:

```

1 -----
2 | Welcome to ROOT 6.22/02                                     https://root.cern |
3 | (c) 1995-2020, The ROOT Team; conception: R. Brun, F. Rademakers |
4 | Built for linuxx8664gcc on Aug 17 2020, 12:46:52             |
5 | From tags/v6-22-02@v6-22-02                                 |
6 | Try '.help', '.demo', '.license', '.credits', '.quit'/'.q' |
7 -----
8
9
10 Processing CrossSectionPlot.C...
11 39 Number items found!
12
13 *****
14 Minimizer is Minuit / Migrad
15 Chi2                =          9658.59
16 NDf                 =              16
17 Edm                 =      8.75461e-10
18 NCalls              =              244

```

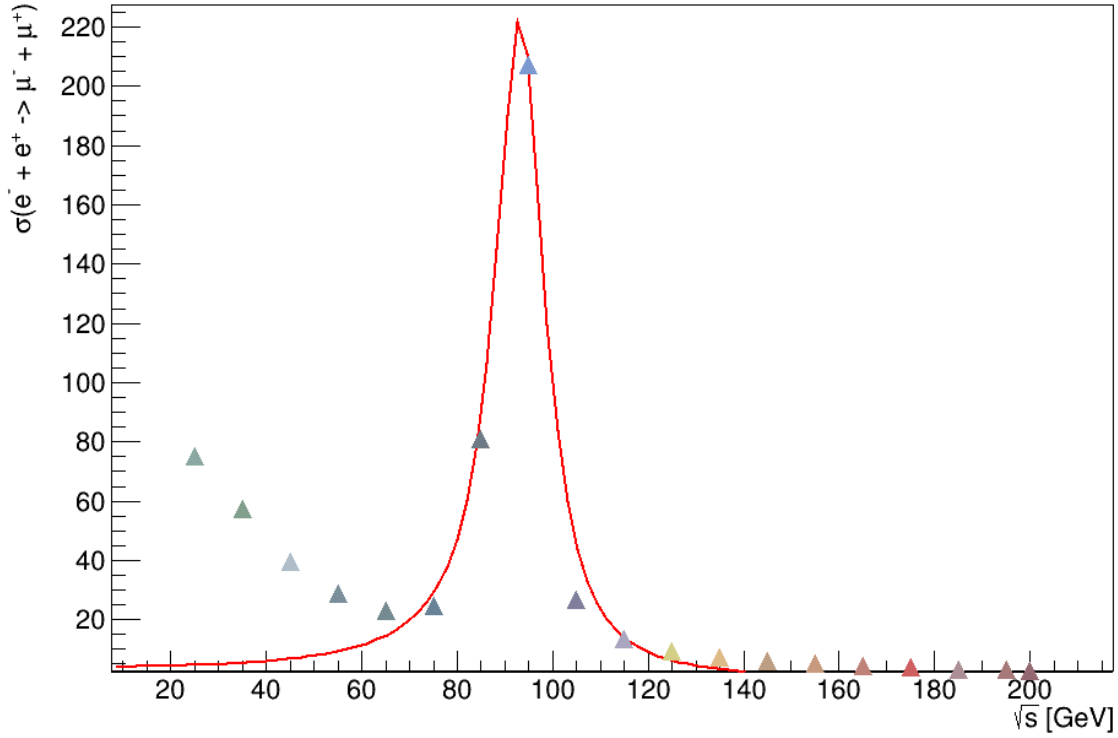


Figure 2: Cross section for the $e^- + e^+ \rightarrow \mu^- + \mu^+$ scattering process

19	p0	=	93.1228	+/-	1.4638
20	p1	=	1.20274e+10	+/-	7.47452e+09
21	p2	=	2.97051e-06	+/-	7.65795e-07

4 Conceptual Problems

4.1 Detectors

In order to calculate the threshold energy above which charged particles emit Cerenkov radiation in water, which have a refractive index $n = 1.33$, can be obtained from the condition

$$\frac{c}{nv} \leq 1 \quad (1)$$

In this way, from (1) we obtain that the minimum velocity that a charged particle must have in order to emit Cerenkov radiation in water is given by

$$v_{\min} = 0.752c. \quad (2)$$

Now, we want to compute the threshold energy. To achieve that we need to consider the relativistic formulas for the energy and the momenta:

$$p = \frac{mv}{\sqrt{1 - \beta^2}}, \quad E = mc^2 \sqrt{1 + \left(\frac{p}{mc^2}\right)^2}, \quad (3)$$

where $\beta = v/c$.

In this way, if we consider electrons ($m = 0.51$ MeV) and muons ($m = 105.658$ MeV), and furthermore by using the formulas (3) we obtain that the threshold energy for electron and muons are respectively:

$$E = 0.77 \text{ MeV}, \quad E = 160.28 \text{ MeV}. \quad (4)$$

Solar neutrino flux

The energy from the sun originates thanks to nuclear reactions which takes places in its central core. The net reaction is

$$4p \rightarrow {}^2\text{He} + 2e^+ + 2\nu_e + 26.2\text{MeV}.$$

In this way the neutrinos leaves the surface of the sun in about 2s after the creation at the core and reaches at the neutrinos detectors in the surface earth.

On the other hand, low energy solar neutrinos mostly interact with electrons in the water Cherenkov detector. The electron neutrinos undergo charged and neutral current interactions whereas the oscillated ν_μ and ν_τ interact only through the neutral current.

Flavor ratio of atmospheric neutrinos

The cosmic rays, which are composed primarily of protons, interact with molecules in the atmosphere and produce pions and kaons. Then, these particles undergo the decays $\pi/K \rightarrow \mu + \nu_\mu$ and $\mu \rightarrow e + \nu_\mu + \nu_e$. These neutrinos reach the neutrino detectors in the earth surface, and interact with the water of the detector. When this interaction happens, secondary particles are produced, and if these particles propagate faster than the phase velocity of the light in the water, then we obtain Cherenkov radiation.

Now, in order to study the neutrino oscillation, which is crucial to understand the flavour ratio, we need to know the types of the secondary showers of particles. Indeed, the ν_e interaction produces an electron in the detector, which produces electromagnetic showers. On the other hand, the $\nu_{\mu\tau}$ interaction produces a muon, which doesn't produce electromagnetic showers. In this way, the ring image of the Cherenkov radiation produced in the beginning by an electron is the summation of the ring images of many electrons and positrons in the electromagnetic shower and shows a fuzzy ring pattern. Therefore, it is possible to separate Cherenkov rings due to an electron and muon and shows a clearer ring pattern. In this way, we can predict the ν_μ/ν_e ratio.

4.2 Standard Model

We have that the quarks come in 3 colours and they interact via the exchange of massless coloured spin-1 gluons. On the other hand, we have that the gauge group of QCD is $SU(3)$. This group is associated with 3×3 unitary matrices. A general complex 3×3 matrix requires $3 \times 3 \times 2 = 18$ real parameters to specify it. As the matrices are unitary, they must satisfy $U^\dagger U = I$. For the off-diagonal terms, both the real and imaginary parts must be equal to 0. There are 6 off-diagonal elements, but if the (i, j) element of the product is 0, then the (j, i) element will also be 0. Therefore, there are 3 off-diagonal elements to consider, each of which provides 2 constraints. So the total number of constraints is $3 + 2 \times 3 = 9$, which leaves 9 parameters. Now, we have that

$$\det(U^\dagger U) = \det(I) = 1. \tag{5}$$

However, $U^\dagger = U^{T*}$, which implies that $\det(U^\dagger) = \det(U^T)^*$, so we obtain that $\det(U) \det(U)^* = 1$, i.e. $\det(U) = e^{i\phi}$. The special unitary group $SU(3)$ has the additional constraint that $\det(U) = +1$. This additional constraint means that we need 8 parameters and there are 8 generators for $SU(3)$ and therefore **8 gluons**.