Tarea II: Física Experimental
Name: Sebastián Fuenzalida Garrido

1 Exercise: Histograms

C++ macro:

```
#include "TCanvas.h"
#include "TROOT.h"
#include "TGraphErrors.h"
#include "TF1.h"
#include "TH1F.h"
#include "TLegend.h"
#include "TFile.h"
#include "TArrow.h"
#include "TLatex.h"
#include "TMath.h"
#include "TMultiGraph.h"

#include <iostream>
#include <math.h>
#include <vector>
#include <stdlib.h>
#include <string>

using namespace std;

class Histogram
{
    protected:
        vector<double> x1, x;
        //Histogram with 10 bins ranging from 0 to 100
        TH1F *h1 = new TH1F("h1", "Histogram; x; Events", 10, 0, 100);
        TGraph *g1 = new TGraph();
    public:
        Histogram () {};

        void FillHistogram()
        {
            //Fill the histogram with three differents numbers
            x1.push_back(11.3); x1.push_back(25.4); x1.push_back(18.1);

            for (unsigned int i = 0; i < x1.size(); ++i)
            {
                h1 -> Fill(x1.at(i));
            }

            //Fill the histogram with the square and square-root of all integers from 0 to 9
            x1.clear();

            for (unsigned int i = 0; i <= 9; ++i)
            {
                x1.push_back(pow(i, 2));
                h1 -> Fill(x1.at(i));
```

```
48              }
49
50              x1.clear();
51
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 cuadratic 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 cuadratic
    function
71                  g1 -> SetPoint(i, x.at(i), x1.at(i));
72              }
73
74              g1 -> Draw("same*l");
75              c1 -> Print("histogram_C.png");
76
77              //Mean value and rms of the derivative of the cuadratic 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, "");
```

```
            cout << "Histogram integral +- error = " << integral << " +- " << error
    << endl;

            //Identify the bin with the maxmun number of entries
            for (unsigned int i = 1; i <= 10; ++i)
            {
                cout << "Bin number: " << i << " Number of entries: " << h1 ->
   GetBinContent(i) << endl;
            }
        }

        virtual ~Histogram () {};
};


void ExerciseHist()
{
    Histogram *obj1 = new Histogram();
    obj1 -> FillHistogram();
}
```

Python **macro:**

```
import ROOT
import numpy as np

class Histogram:
    def __init__(self, data1, data2):
        hist = ROOT.TH1F("variable", "Histogram; x; events", 10, 0, 100)
        g1 = ROOT.TGraph()

        for i in range(data1.size):
            hist.Fill(data1[i])

        for i in range(data2.size):
            g1.SetPoint(i, i, data2[i])

        print('Histogram integral: ' + str(hist.Integral()))

        for i in range(1, 11):
            print("Bin number: " + str(i) + ' Number of entries: ' + str(hist.
   GetBinContent(i)))

        c1 = ROOT.TCanvas("c1", "c1", 1024, 800)
        hist.Draw()
        g1.Draw("same*l")
        c1.Print("histogram_python_ROOT.png")

class MeanAndRMS:
    def __init__(self, data):
        counter1 = 0
        for i in range(0, data.size):
            counter1 += data[i]
        mean = counter1/data.size
        print('Mean derivative square function: ' + str(mean))

        counter2 = 0
```

```
        for i in range(0, data.size):
            counter2 += data[i]**2
        RMS = np.sqrt(counter2/data.size)
        print('RMS derivative square function: ' + str(RMS))

data_list_1 = [11.3, 25.4, 18.1]
data_list_2 = []

for i in range(0, 10):
    data_list_1.append(i**2)
    data_list_1.append(np.sqrt(i))

f1 = ROOT.TF1("func1","x**2", 0, 10)

for i in range(0, 10):
    data_list_2.append(f1.Derivative(i))

data_np_array_1 = np.array(data_list_1)
data_np_array_2 = np.array(data_list_2)

obj1 = Histogram(data_np_array_1, data_np_array_2)
obj2 = MeanAndRMS(data_np_array_2)
```

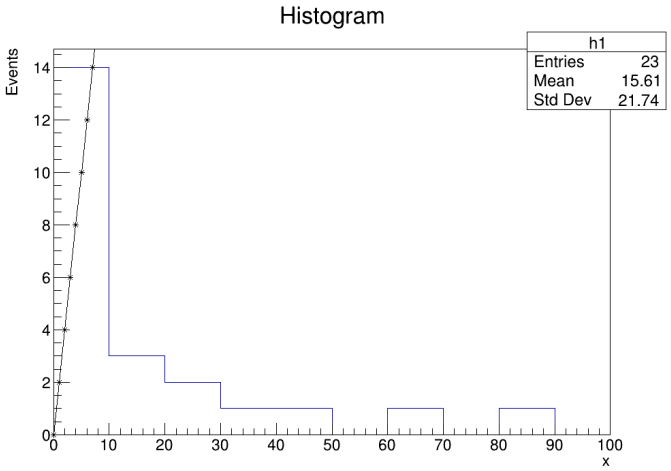
Output C++ macro:

```
   ------------------------------------------------------------
  | Welcome to ROOT 6.10/06                 http://root.cern.ch |
  |                                (c) 1995-2017, The ROOT Team |
  | Built for linuxx8664gcc                                     |
  | From tag v6-10-06, 19 September 2017                        |
  | Try '.help', '.demo', '.license', '.credits', '.quit'/'.q' |
   ------------------------------------------------------------


Processing ExerciseHist.C...
Mean derivative square function: 8
RMS derivative square function: 10.6301
Histogram integral +- error = 23 +- 4.79583
Bin number: 1 Number of entries: 14
Bin number: 2 Number of entries: 3
Bin number: 3 Number of entries: 2
Bin number: 4 Number of entries: 1
Bin number: 5 Number of entries: 1
Bin number: 6 Number of entries: 0
Bin number: 7 Number of entries: 1
Bin number: 8 Number of entries: 0
Bin number: 9 Number of entries: 1
Bin number: 10 Number of entries: 0
```

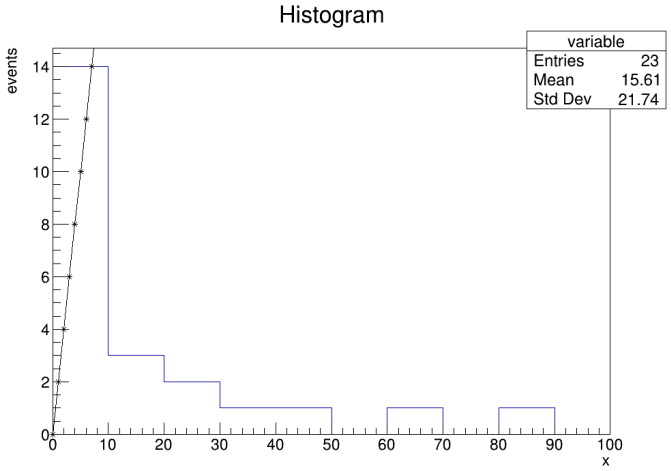
Output Python macro:

```
Histogram integral: 23.0
Bin number: 1 Number of entries: 14.0
Bin number: 2 Number of entries: 3.0
Bin number: 3 Number of entries: 2.0
Bin number: 4 Number of entries: 1.0
Bin number: 5 Number of entries: 1.0
Bin number: 6 Number of entries: 0.0
```

```
Bin number: 7 Number of entries: 1.0
Bin number: 8 Number of entries: 0.0
Bin number: 9 Number of entries: 1.0
Bin number: 10 Number of entries: 0.0
Mean derivative square function: 9.0
RMS derivative square function: 10.677078252
```



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



(b) Output histogram of the Python code.

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

2.1 Generating the process

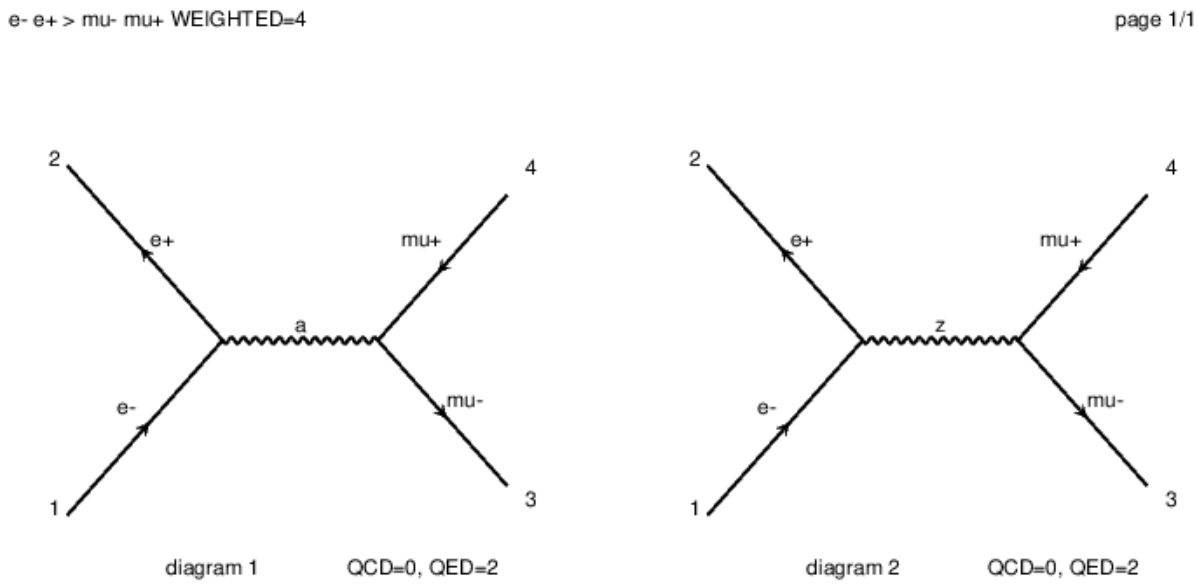
Output:

```
************************************************************
*                                                          *
*                      W E L C O M E to                    *
*               M A D G R A P H 5 _ a M C @ N L O          *
*                                                          *
*                                                          *
*                  *                       *               *
*                    *        * *        *                 *
*                      * * * * 5 * * * *                   *
*                    *        * *        *                 *
*                  *                       *               *
*                                                          *
*         VERSION 3.1.0                2021-03-30          *
*                                                          *
*    The MadGraph5_aMC@NLO Development Team - Find us at   *
*    https://server06.fynu.ucl.ac.be/projects/madgraph     *
*                           and                            *
*            http://amcatnlo.web.cern.ch/amcatnlo/         *
*                                                          *
*               Type 'help' for in-line help.              *
*           Type 'tutorial' to learn how MG5 works         *
*    Type 'tutorial aMCatNLO' to learn how aMC@NLO works   *
*    Type 'tutorial MadLoop' to learn how MadLoop works    *
```

```
*                                                            *
************************************************************
load MG5 configuration from ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/input/
   mg5_configuration.txt
fastjet-config does not seem to correspond to a valid fastjet-config executable (v3
   +). We will use fjcore instead.
 Please set the 'fastjet'variable to the full (absolute) /PATH/TO/fastjet-config (
   including fastjet-config).
 MG5_aMC> set fastjet /PATH/TO/fastjet-config

set lhapdf to lhapdf-config
/user/e/edson/public/exp_phys/MG5_aMC_v3_1_0/HEPTools/lhapdf6_py3/bin/lhapdf-config
    does not seem to correspond to a valid lhapdf-config executable.
Please set the 'lhapdf' variable to the (absolute) /PATH/TO/lhapdf-config (
   including lhapdf-config).
Note that you can still compile and run aMC@NLO with the built-in PDFs
 MG5_aMC> set lhapdf /PATH/TO/lhapdf-config

Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
Using default eps viewer "gv". Set another one in ./input/mg5_configuration.txt
No valid web browser found. Please set in ./input/mg5_configuration.txt
import /user/e/exphys02/TareaIIFisicaExp/Problema2/Item21/run.dat
The import format was not given, so we guess it as command


generate e- e+ > mu- mu+
No model currently active, so we import the Standard Model
INFO: Restrict model sm with file ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/
   models/sm/restrict_default.dat .
INFO: Run "set stdout_level DEBUG" before import for more information.
INFO: Change particles name to pass to MG5 convention
Defined multiparticle p = g u c d s u~ c~ d~ s~
Defined multiparticle j = g u c d s u~ c~ d~ s~
Defined multiparticle l+ = e+ mu+
Defined multiparticle l- = e- mu-
Defined multiparticle vl = ve vm vt
Defined multiparticle vl~ = ve~ vm~ vt~
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+
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying process: e- e+ > mu- mu+ WEIGHTED<=4 @1
INFO: Process has 2 diagrams
1 processes with 2 diagrams generated in 0.006 s
Total: 1 processes with 2 diagrams


display processes
Process: e- e+ > mu- mu+ WEIGHTED<=4 @1


display diagrams
Drawing Process: e- e+ > mu- mu+ WEIGHTED<=4 @1
Wrote file /tmp/diagrams_1_emep_mummup.eps
open /tmp/diagrams_1_emep_mummup.eps
time to draw 0.004775524139404297
```

```
73 quit
```

Feynman diagrams:



2.2 Exporting the process

Output:

```
************************************************************
*                                                          *
*                      W E L C O M E to                    *
*              M A D G R A P H 5 _ a M C @ N L O           *
*                                                          *
*                                                          *
*                 *                       *                *
*                   *        * *        *                  *
*                     * * * * 5 * * * *                    *
*                   *        * *        *                  *
*                 *                       *                *
*                                                          *
*         VERSION 3.1.0                 2021-03-30         *
*                                                          *
*    The MadGraph5_aMC@NLO Development Team - Find us at   *
*    https://server06.fynu.ucl.ac.be/projects/madgraph     *
*                           and                            *
*            http://amcatnlo.web.cern.ch/amcatnlo/         *
*                                                          *
*               Type 'help' for in-line help.              *
*           Type 'tutorial' to learn how MG5 works         *
*    Type 'tutorial aMCatNLO' to learn how aMC@NLO works   *
*    Type 'tutorial MadLoop' to learn how MadLoop works    *
*                                                          *
************************************************************
load MG5 configuration from ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/input/mg5_configuration.txt
fastjet-config does not seem to correspond to a valid fastjet-config executable (v3+). We will use fjcore instead.
 Please set the 'fastjet'variable to the full (absolute) /PATH/TO/fastjet-config (including fastjet-config).
 MG5_aMC> set fastjet /PATH/TO/fastjet-config

set lhapdf to lhapdf-config
/user/e/edson/public/exp_phys/MG5_aMC_v3_1_0/HEPTools/lhapdf6_py3/bin/lhapdf-config does not seem to correspond to a valid lhapdf-config executable.
Please set the 'lhapdf' variable to the (absolute) /PATH/TO/lhapdf-config (including lhapdf-config).
Note that you can still compile and run aMC@NLO with the built-in PDFs
 MG5_aMC> set lhapdf /PATH/TO/lhapdf-config

Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
Using default eps viewer "gv". Set another one in ./input/mg5_configuration.txt
No valid web browser found. Please set in ./input/mg5_configuration.txt
import /user/e/exphys02/TareaIIFisicaExp/Problema2/Item22/run.dat
The import format was not given, so we guess it as command


generate e- e+ > mu- mu+
No model currently active, so we import the Standard Model
INFO: Restrict model sm with file ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/models/sm/restrict_default.dat .
INFO: Run "set stdout_level DEBUG" before import for more information.
```

```
INFO: Change particles name to pass to MG5 convention
Defined multiparticle p = g u c d s u~ c~ d~ s~
Defined multiparticle j = g u c d s u~ c~ d~ s~
Defined multiparticle l+ = e+ mu+
Defined multiparticle l- = e- mu-
Defined multiparticle vl = ve vm vt
Defined multiparticle vl~ = ve~ vm~ vt~
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+
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying process: e- e+ > mu- mu+ WEIGHTED<=4 @1
INFO: Process has 2 diagrams
1 processes with 2 diagrams generated in 0.006 s
Total: 1 processes with 2 diagrams


output MYFIRSTPROCESS
INFO: initialize a new directory: MYFIRSTPROCESS
INFO: remove old information in MYFIRSTPROCESS
INFO: Organizing processes into subprocess groups
INFO: Generating Helas calls for process: e- e+ > mu- mu+ WEIGHTED<=4 @1
INFO: Processing color information for process: e- e+ > mu- mu+ @1
INFO: Creating files in directory P1_ll_ll
INFO: Generating Feynman diagrams for Process: e- e+ > mu- mu+ WEIGHTED<=4 @1
INFO: Finding symmetric diagrams for subprocess group ll_ll
Generated helas calls for 1 subprocesses (2 diagrams) in 0.004 s
Wrote files for 8 helas calls in 0.994 s
ALOHA: aloha starts to compute helicity amplitudes
ALOHA: aloha creates 3 routines in  4.011 s
save configuration file to /user/e/exphys02/TareaIIFisicaExp/Problema2/Item22/
   MYFIRSTPROCESS/Cards/me5_configuration.txt
INFO: Use Fortran compiler gfortran
INFO: Use c++ compiler g++
INFO: Generate jpeg diagrams
INFO: Generate web pages
Output to directory /user/e/exphys02/TareaIIFisicaExp/Problema2/Item22/
   MYFIRSTPROCESS done.
Type "launch" to generate events from this process, or see
/user/e/exphys02/TareaIIFisicaExp/Problema2/Item22/MYFIRSTPROCESS/README
Run "open index.html" to see more information about this process.
quit
```

2.3 Launching the process

Output:

```
************************************************************
*                                                          *
*                    W E L C O M E to                      *
*              M A D G R A P H 5 _ a M C @ N L O           *
*                                                          *
*                                                          *
*                 *                       *                *
*                   *        * *        *                  *
```

```
*                      * * * * 5 * * * *                       *
*                    *         * *         *                    *
*                  *                         *                  *
*                                                              *
*         VERSION 3.1.0                 2021-03-30             *
*                                                              *
*    The MadGraph5_aMC@NLO Development Team - Find us at       *
*    https://server06.fynu.ucl.ac.be/projects/madgraph         *
*                            and                               *
*            http://amcatnlo.web.cern.ch/amcatnlo/             *
*                                                              *
*               Type 'help' for in-line help.                  *
*           Type 'tutorial' to learn how MG5 works             *
*    Type 'tutorial aMCatNLO' to learn how aMC@NLO works       *
*    Type 'tutorial MadLoop' to learn how MadLoop works        *
*                                                              *
****************************************************************
load MG5 configuration from ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/input/
   mg5_configuration.txt
fastjet-config does not seem to correspond to a valid fastjet-config executable (v3
   +). We will use fjcore instead.
 Please set the 'fastjet'variable to the full (absolute) /PATH/TO/fastjet-config (
   including fastjet-config).
 MG5_aMC> set fastjet /PATH/TO/fastjet-config

set lhapdf to lhapdf-config
/user/e/edson/public/exp_phys/MG5_aMC_v3_1_0/HEPTools/lhapdf6_py3/bin/lhapdf-config
    does not seem to correspond to a valid lhapdf-config executable.
Please set the 'lhapdf' variable to the (absolute) /PATH/TO/lhapdf-config (
   including lhapdf-config).
Note that you can still compile and run aMC@NLO with the built-in PDFs
 MG5_aMC> set lhapdf /PATH/TO/lhapdf-config

Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
Using default eps viewer "gv". Set another one in ./input/mg5_configuration.txt
No valid web browser found. Please set in ./input/mg5_configuration.txt
import /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/run.dat
The import format was not given, so we guess it as command


generate e- e+ > mu- mu+
No model currently active, so we import the Standard Model
INFO: Restrict model sm with file ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/
   models/sm/restrict_default.dat .
INFO: Run "set stdout_level DEBUG" before import for more information.
INFO: Change particles name to pass to MG5 convention
Defined multiparticle p = g u c d s u~ c~ d~ s~
Defined multiparticle j = g u c d s u~ c~ d~ s~
Defined multiparticle l+ = e+ mu+
Defined multiparticle l- = e- mu-
Defined multiparticle vl = ve vm vt
Defined multiparticle vl~ = ve~ vm~ vt~
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+
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
```

```
INFO: Trying process: e- e+ > mu- mu+ WEIGHTED<=4 @1
INFO: Process has 2 diagrams
1 processes with 2 diagrams generated in 0.006 s
Total: 1 processes with 2 diagrams


output MYFIRSTPROCESS
INFO: initialize a new directory: MYFIRSTPROCESS
INFO: remove old information in MYFIRSTPROCESS
INFO: Organizing processes into subprocess groups
INFO: Generating Helas calls for process: e- e+ > mu- mu+ WEIGHTED<=4 @1
INFO: Processing color information for process: e- e+ > mu- mu+ @1
INFO: Creating files in directory P1_ll_ll
INFO: Generating Feynman diagrams for Process: e- e+ > mu- mu+ WEIGHTED<=4 @1
INFO: Finding symmetric diagrams for subprocess group ll_ll
Generated helas calls for 1 subprocesses (2 diagrams) in 0.010 s
Wrote files for 8 helas calls in 1.436 s
ALOHA: aloha starts to compute helicity amplitudes
ALOHA: aloha creates 3 routines in  3.361 s
save configuration file to /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/
   MYFIRSTPROCESS/Cards/me5_configuration.txt
INFO: Use Fortran compiler gfortran
INFO: Use c++ compiler g++
INFO: Generate jpeg diagrams
INFO: Generate web pages
Output to directory /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/
   MYFIRSTPROCESS done.
Type "launch" to generate events from this process, or see
/user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/MYFIRSTPROCESS/README
Run "open index.html" to see more information about this process.


launch MYFIRSTPROCESS
************************************************************
*                                                          *
*                      W E L C O M E to                    *
*            M A D G R A P H 5 _ a M C @ N L O             *
*                      M A D E V E N T                     *
*                                                          *
*                  *                       *               *
*                    *        * *        *                 *
*                      * * * * 5 * * * *                   *
*                    *        * *        *                 *
*                  *                       *               *
*                                                          *
*         VERSION 3.1.0                2021-03-30          *
*                                                          *
*    The MadGraph5_aMC@NLO Development Team - Find us at   *
*    https://server06.fynu.ucl.ac.be/projects/madgraph     *
*                                                          *
*               Type 'help' for in-line help.              *
*                                                          *
************************************************************
INFO: load configuration from /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/
   MYFIRSTPROCESS/Cards/me5_configuration.txt
```

```
INFO: load configuration from /user/e/edson/public/exp_phys/MG5_aMC_v3_1_0/input/mg5_configuration.txt
INFO: load configuration from /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/MYFIRSTPROCESS/Cards/me5_configuration.txt
Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
No valid web browser found. Please set in ./input/mg5_configuration.txt
generate_events run_01
The following switches determine which programs are run:
/================== Description ==================|============ values ==============|===== other options =====\
| 1. Choose the shower/hadronization program       |             shower  =  OFF      |     Pythia8             |
| 2. Choose the detector simulation program        |           detector  =  OFF      |     Delphes             |
| 3. Choose an analysis package (plot/convert)     |           analysis  =  ExRoot   |     OFF                 |
| 4. Decay onshell particles                       |           madspin   =  OFF      |     ON|onshell|full     |
| 5. Add weights to events for new hypp.           |          reweight   =  OFF      |     ON                  |
\=================================================================================================================

Either type the switch number (1 to 5) to change its setting,
Set any switch explicitly (e.g. type 'shower=Pythia8' at the prompt)
Type 'help' for the list of all valid option
Type '0', 'auto', 'done' or just press enter when you are done.
The answer to the previous question is not set in your input file
Use 0 value
Do you want to edit a card (press enter to bypass editing)?
/-----------------------------------------------------------\
|                param :       param_card.dat               |
|                run   :       run_card.dat                 |
\-----------------------------------------------------------/
 you can also
   - enter the path to a valid card or banner.
   - use the 'set' command to modify a parameter directly.
     The set option works only for param_card and run_card.
     Type 'help set' for more information on this command.
   - call an external program (ASperGE/MadWidth/...).
     Type 'help' for the list of available command
     0, done, 1, param, 2, run, enter path
    The answer to the previous question is not set in your input file
    Use 0 value
INFO: Update the dependent parameter of the param_card.dat
Generating 10000 events with run name run_01
survey  run_01
INFO: compile directory
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
compile Source Directory
Using random number seed offset = 21
INFO: Running Survey
Creating Jobs
```

```
Working on SubProcesses
INFO: Compiling for process 1/1.
INFO:     P1_ll_ll
INFO:     P1_ll_ll
INFO:  Idle: 1,  Running: 0,  Completed: 0 [ current time: 22h06 ]
INFO:  Idle: 0,  Running: 0,  Completed: 1 [  1.5s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 1 [  1.5s  ]
INFO: End survey
refine 10000
Creating Jobs
INFO: Refine results to 10000
INFO: Generating 10000.0 unweighted events.
sum of cpu time of last step: 0 second
INFO: Effective Luminosity 115063.76450282866 pb^-1
INFO: need to improve 2 channels
- Current estimate of cross-section: 0.10429 +- 0.0003023733999544272
    P1_ll_ll
INFO:  Idle: 1,  Running: 12,  Completed: 0 [ current time: 22h06 ]
INFO:  Idle: 0,  Running: 12,  Completed: 1 [  1.2s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 13 [  2.2s  ]
INFO: Combining runs
sum of cpu time of last step: 8 seconds
INFO: finish refine
refine 10000 --treshold=0.9
No need for second refine due to stability of cross-section
INFO: Combining Events
  === Results Summary for run: run_01 tag: tag_1 ===

     Cross-section :   0.1042 +- 7.702e-05 pb
     Nb of events :  10000

store_events
INFO: Storing parton level results
INFO: End Parton
reweight -from_cards
decay_events -from_cards
INFO: Creating root files
** Reading /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/MYFIRSTPROCESS/Events
   /run_01/unweighted_events.lhe
** Exiting...
INFO: storing files of previous run
INFO: Done
quit
INFO:
more information in /user/e/exphys02/TareaIIFisicaExp/Problema2/Item23/
   MYFIRSTPROCESS/index.html
quit
```

2.4 The CM energy collision

Output:

```
************************************************************
*                                                          *
*                    W E L C O M E to                      *
```

```
*               M A D G R A P H 5 _ a M C @ N L O               *
*                                                               *
*                                                               *
*                  *                        *                   *
*                    *        * *         *                     *
*                      * * * * 5 * * * *                        *
*                    *        * *         *                     *
*                  *                        *                   *
*                                                               *
*         VERSION 3.1.0                 2021-03-30              *
*                                                               *
*    The MadGraph5_aMC@NLO Development Team - Find us at        *
*    https://server06.fynu.ucl.ac.be/projects/madgraph          *
*                           and                                 *
*            http://amcatnlo.web.cern.ch/amcatnlo/              *
*                                                               *
*               Type 'help' for in-line help.                   *
*           Type 'tutorial' to learn how MG5 works              *
*    Type 'tutorial aMCatNLO' to learn how aMC@NLO works        *
*    Type 'tutorial MadLoop' to learn how MadLoop works         *
*                                                               *
*****************************************************************
load MG5 configuration from ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/input/
   mg5_configuration.txt
fastjet-config does not seem to correspond to a valid fastjet-config executable (v3
   +). We will use fjcore instead.
 Please set the 'fastjet'variable to the full (absolute) /PATH/TO/fastjet-config (
   including fastjet-config).
 MG5_aMC> set fastjet /PATH/TO/fastjet-config

set lhapdf to lhapdf-config
/user/e/edson/public/exp_phys/MG5_aMC_v3_1_0/HEPTools/lhapdf6_py3/bin/lhapdf-config
    does not seem to correspond to a valid lhapdf-config executable.
Please set the 'lhapdf' variable to the (absolute) /PATH/TO/lhapdf-config (
   including lhapdf-config).
Note that you can still compile and run aMC@NLO with the built-in PDFs
 MG5_aMC> set lhapdf /PATH/TO/lhapdf-config

Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
Using default eps viewer "gv". Set another one in ./input/mg5_configuration.txt
No valid web browser found. Please set in ./input/mg5_configuration.txt
import /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/run.dat
The import format was not given, so we guess it as command


generate e- e+ > mu- mu+
No model currently active, so we import the Standard Model
INFO: Restrict model sm with file ../../../../edson/public/exp_phys/MG5_aMC_v3_1_0/
   models/sm/restrict_default.dat .
INFO: Run "set stdout_level DEBUG" before import for more information.
INFO: Change particles name to pass to MG5 convention
Defined multiparticle p = g u c d s u~ c~ d~ s~
Defined multiparticle j = g u c d s u~ c~ d~ s~
Defined multiparticle l+ = e+ mu+
Defined multiparticle l- = e- mu-
Defined multiparticle vl = ve vm vt
```

```
Defined multiparticle vl~ = ve~ vm~ vt~
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+
INFO: Checking for minimal orders which gives processes.
INFO: Please specify coupling orders to bypass this step.
INFO: Trying process: e- e+ > mu- mu+ WEIGHTED<=4 @1
INFO: Process has 2 diagrams
1 processes with 2 diagrams generated in 0.006 s
Total: 1 processes with 2 diagrams


output MYFIRSTPROCESS
INFO: initialize a new directory: MYFIRSTPROCESS
INFO: remove old information in MYFIRSTPROCESS
INFO: Organizing processes into subprocess groups
INFO: Generating Helas calls for process: e- e+ > mu- mu+ WEIGHTED<=4 @1
INFO: Processing color information for process: e- e+ > mu- mu+ @1
INFO: Creating files in directory P1_ll_ll
INFO: Generating Feynman diagrams for Process: e- e+ > mu- mu+ WEIGHTED<=4 @1
INFO: Finding symmetric diagrams for subprocess group ll_ll
Generated helas calls for 1 subprocesses (2 diagrams) in 0.012 s
Wrote files for 8 helas calls in 1.568 s
ALOHA: aloha starts to compute helicity amplitudes
ALOHA: aloha creates 3 routines in  2.962 s
save configuration file to /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/
   MYFIRSTPROCESS/Cards/me5_configuration.txt
INFO: Use Fortran compiler gfortran
INFO: Use c++ compiler g++
INFO: Generate jpeg diagrams
INFO: Generate web pages
Output to directory /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/
   MYFIRSTPROCESS done.
Type "launch" to generate events from this process, or see
/user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/MYFIRSTPROCESS/README
Run "open index.html" to see more information about this process.


launch MYFIRSTPROCESS
************************************************************
*                                                          *
*                    W E L C O M E to                      *
*             M A D G R A P H 5 _ a M C @ N L O            *
*                    M A D E V E N T                       *
*                                                          *
*                 *                       *                *
*                   *        * *        *                  *
*                     * * * * 5 * * * *                    *
*                   *        * *        *                  *
*                 *                       *                *
*                                                          *
*         VERSION 3.1.0                2021-03-30          *
*                                                          *
*    The MadGraph5_aMC@NLO Development Team - Find us at   *
*    https://server06.fynu.ucl.ac.be/projects/madgraph     *
*                                                          *
*               Type 'help' for in-line help.              *
```

```
*                                                            *
************************************************************
INFO: load configuration from /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/
   MYFIRSTPROCESS/Cards/me5_configuration.txt
INFO: load configuration from /user/e/edson/public/exp_phys/MG5_aMC_v3_1_0/input/
   mg5_configuration.txt
INFO: load configuration from /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/
   MYFIRSTPROCESS/Cards/me5_configuration.txt
Using default text editor "vi". Set another one in ./input/mg5_configuration.txt
No valid web browser found. Please set in ./input/mg5_configuration.txt
generate_events run_01
set ebeam1 100
INFO: modify parameter ebeam1 of the run_card.dat to 100.0
set ebeam2 100
INFO: modify parameter ebeam2 of the run_card.dat to 100.0
INFO: Update the dependent parameter of the param_card.dat
Generating 10000 events with run name run_01
survey  run_01
INFO: compile directory
Not able to open file /user/e/exphys02/TareaIIFisicaExp/Problema2/Item24/
   MYFIRSTPROCESS/crossx.html since no program configured.Please set one in ./
   input/mg5_configuration.txt
compile Source Directory
Using random number seed offset = 21
INFO: Running Survey
Creating Jobs
Working on SubProcesses
INFO: Compiling for process 1/1.
INFO:     P1_ll_ll
INFO:     P1_ll_ll
INFO:  Idle: 1,  Running: 0,  Completed: 0 [ current time: 22h18 ]
INFO:  Idle: 0,  Running: 0,  Completed: 1 [  1.3s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 1 [  1.4s  ]
INFO: End survey
refine 10000
Creating Jobs
INFO: Refine results to 10000
INFO: Generating 10000.0 unweighted events.
sum of cpu time of last step: 0 second
INFO: Effective Luminosity 4298.1482144775955 pb^-1
INFO: need to improve 2 channels
- Current estimate of cross-section: 2.7919 +- 0.008363567345337754
    P1_ll_ll
INFO:  Idle: 1,  Running: 12,  Completed: 0 [ current time: 22h18 ]
INFO:  Idle: 0,  Running: 10,  Completed: 3 [  1s  ]
INFO:  Idle: 0,  Running: 0,  Completed: 13 [  2.7s  ]
INFO: Combining runs
sum of cpu time of last step: 9 seconds
INFO: finish refine
refine 10000 --treshold=0.9
No need for second refine due to stability of cross-section
INFO: Combining Events
  === Results Summary for run: run_01 tag: tag_1 ===

     Cross-section :   2.789 +- 0.002403 pb
     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:
```

```
        ReadingFileVariables() {};
        virtual ~ ReadingFileVariables() {};
};

class ReadingFile: public ReadingFileVariables
{
    public:
        ReadingFile () {};

        void OpenFileOne(string aux_string)
        {
            inFile1.open(aux_string);
        }

        void CheckForErrorOne()
        {
            if(inFile1.fail())
            {
                cerr << "Error opening the file :(" << endl; //Error message
                exit(1);
            }
        }

        void ReadTheElementsOfTheFileNumbers()
        {
            counter_numbers = 0;

            while (!inFile1.eof())
            {
                inFile1 >> numbers_items;
                numbers_vector.push_back(numbers_items);
                ++counter_numbers;
            }

            cout << counter_numbers << " Number items found!" << endl;
        }

        void ShowTheElementsOfTheFileNumbers()
        {
            for (int i = 0; i < numbers_vector.size(); ++i)
            {
                cout << numbers_vector.at(i) << endl;
            }
        }

        void CloseFileOne(){inFile1.close();}

        ~ ReadingFile () {};
};

class Plot: public ReadingFile
{
    private:
        vector<double> total_vector;
        vector<double> cross_section_vector;
        vector<double> CM_energy;
```

```
    public:
        Plot () {};

        void PlotCrossSection ()
        {
            for (unsigned int i = 0; i < numbers_vector.size(); ++i)
            {
                total_vector.push_back(numbers_vector.at(i));
            }

            for (unsigned int i = 0; i < total_vector.size()/2; ++i)
            {
                cross_section_vector.push_back(total_vector.at(i));
            }

            for (unsigned int i = total_vector.size()/2; i < total_vector.size() - 1; ++i)
            {
                CM_energy.push_back(total_vector.at(i));
            }

            TGraph *g1 = new TGraph(CM_energy.size(), &CM_energy[0], &cross_section_vector[0]);
            TCanvas *c1 = new TCanvas("c1", "c1", 1024, 800);

            TF1 *f1 = new TF1("f1", "[2]*[1]*pow([0], 2)/( pow((x*x - pow([0], 2)), 2) + [1]/pow([0], 2) )", 90, 200);

            f1 -> SetParameter(0, 90);
            f1 -> SetParameter(2, 2.9*0.000001);
            g1 -> SetLineColor(21);
            g1 -> Fit("f1");
            g1 -> Draw("AP");
            g1 -> GetXaxis() -> SetTitle("#sqrt{s} [GeV]");
            g1 -> GetYaxis() -> SetTitle("#sigma(e^{-} + e^{+} -> #mu^{-} + #mu^{+})");
            g1 -> SetTitle("");

            double *nx = g1 -> GetX();
            double *ny = g1 -> GetY();

            for (unsigned int j = 0; j < CM_energy.size(); ++j)
            {
                TMarker *m = new TMarker(nx[j], ny[j], 22);
                m -> SetMarkerSize(2);
                m -> SetMarkerColor(31 + j);
                m -> Draw();
            }

            c1 -> Print("plot_problem_3.png");
        }

        ~ Plot () {};
};

void CrossSectionPlot()
```

```
{
    Plot *File1 = new Plot();
    string NameOfFile = "cross_section.txt"; //Name of our data set that is located
    in our local storage drive

    File1 -> OpenFileOne(NameOfFile);
    File1 -> CheckForErrorOne();
    File1 -> ReadTheElementsOfTheFileNumbers();
    //File1 -> ShowTheElementsOfTheFileNumbers();
    File1 -> CloseFileOne();
    File1 -> PlotCrossSection();

    return 0;
}
```

Output C++ macro:

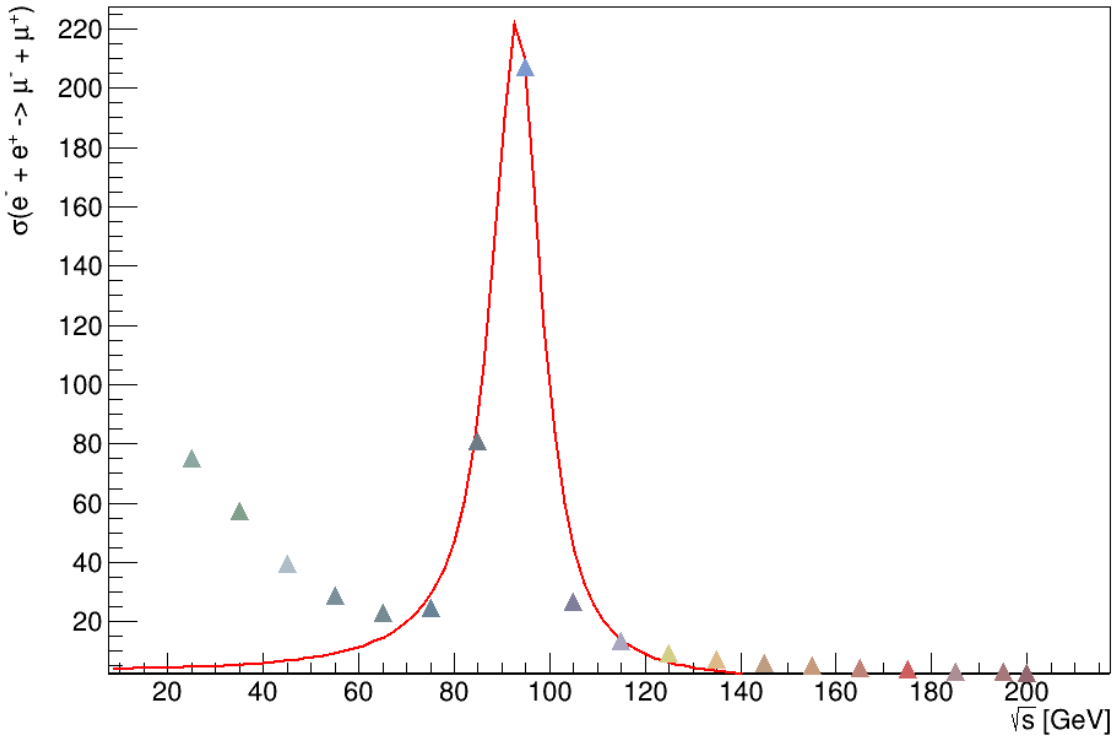


Figure 2: Cross section for the $e^- + e^+ \rightarrow \mu^- + \mu^+$ scattering process

```
 ------------------------------------------------------------------
| Welcome to ROOT 6.22/02                        https://root.cern |
| (c) 1995-2020, The ROOT Team; conception: R. Brun, F. Rademakers |
| Built for linuxx8664gcc on Aug 17 2020, 12:46:52                 |
| From tags/v6-22-02@v6-22-02                                      |
| Try '.help', '.demo', '.license', '.credits', '.quit'/'.q'       |
 ------------------------------------------------------------------


Processing CrossSectionPlot.C...
```

```
39 Number items found!

**************************************
Minimizer is Minuit / Migrad
Chi2                      =      9658.59
NDf                       =           16
Edm                       =  8.75461e-10
NCalls                    =          244
p0                        =      93.1228   +/-   1.4638
p1                        =  1.20274e+10   +/-   7.47452e+09
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

$$\frac{c}{nv} \leq 1 \tag{1}$$

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

$$v_{\min} = 0.752c. \tag{2}$$

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

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

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:

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

Solar neutrino flux

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

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

In this way the neutrinos leaves the surface of the sun in about 2s after the creation at the core an 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 chraged 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 primaraly of protons, interact with molecules in the atmosphere and produce pions and kaons. Then, these particles undergoes the decays $\pi/K \rightarrow \mu + \nu_\mu$ and $\mu \rightarrow e + \nu_\mu + \nu_e$. These neutrinos reaches 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 secundary showers of particles. Indeed, the ν_e interaction produces an electron in the detector, which produces electromagnetic showers. On the other hand, the ν_{mu} interaction produces a muon, which don't produce electromagnetic showers. In this way, the ring image of the Cherenkov radiation produced in the beggining by an electron is the summation of the ring images of many electrons and positrons in the electromagnetic shower and shows fuggy ring pattern. Therefore, it is possible to separate Cherenkov rings due to an electron and muon and shows 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 in 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

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

However, $U^\dagger = U^{T*}$, which implies that $\det\left(U^\dagger\right) = \det\left(U^T\right)^*$, 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**.