Introduction to ROOT (and some python)

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Introduction

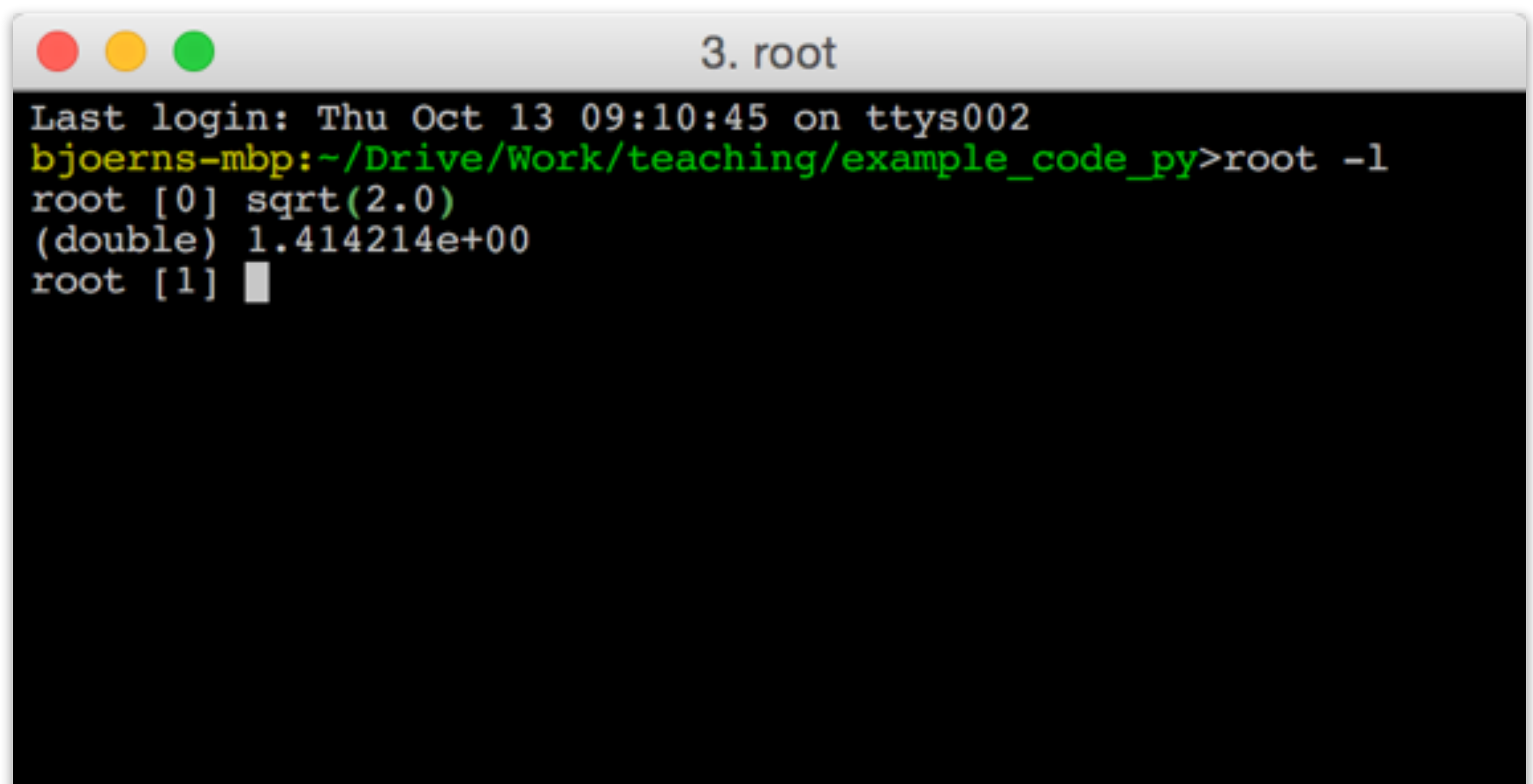
- Elementary techniques for data analysis and visualization with ROOT are discussed.
- This tutorial was until recently all C++, I just changed to python to make it easier to get started. I am not a python expert myself
    - Code: https://dl.dropboxusercontent.com/u/1882892/example_code_py.tar.gz
    - C++ examples are included as well
- ROOT utilizes C++ syntax but programming is fairly easy since ROOT offers a built-in compiler/interpreter.
- Even beginners should be able to gain the necessary skills quickly…
- When discussion code the name of the file is in the title

About ROOT

- ROOT is an object orientated software package for data analysis and visualization. It's based on the C/C++.
- Resource at `http://root.cern.ch`
  - Executables and source course for several OS (Linux, Windows, Mac OS X)
  - User's Guide
  - Reference Guide
  - Tutorials, Howto's etc
  - Mailing list

The ROOT shell

- After installing root on your machine execute in a shell:
  `#>root`
- The `ROOT` shell (CINT) appears, this is `ROOT's` built in interactive C/C++ interpreter
  - Exit using “`.q`”



- Use CINT to enter commands, e.g `sqrt(2)` (see sample left)

First steps

- We will discuss a few simple and short programs that illustrate quite some of the built in power
- You can edit these files with any editor, (e.g. emacs,vi, pico)
- Execute the code by executing ‘#>`python example.py`

Import libraries to the corresponding commands become available

Print text and output of simple calc. Note how we reference the library

```
import ROOT as r
import math

print 'First example:'
print 'Sqrt of 2 = '+str(math.sqrt(2.))
```

Basic histogram operations

- Create a histogram myH1 with 10 bins and a range from 0. to 1. by using:

```
myH1=r.TH1F(“histo”,”distribution 0. to 1.”,10,0.,1.)
```

name

title

number of bins and range

- Insert value x to the histogram by the `Fill()` method

```
myH1.Fill(x)
```

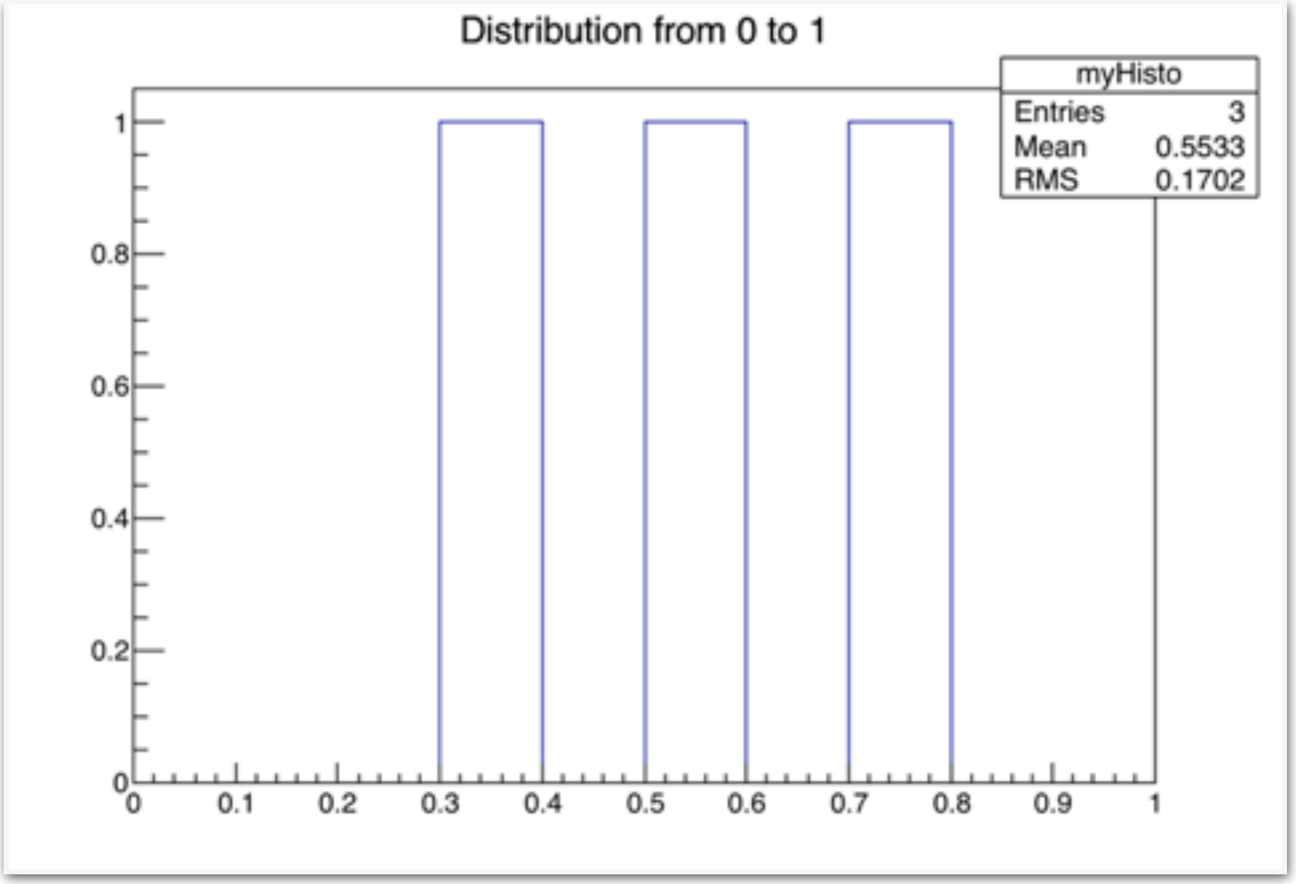
- Draw the histogram by calling the `Draw()` method

```
myH1.Draw()
```

histogram.py

```
import ROOT as r

myH1 = r.TH1F('myHisto', 'Distribution from 0 to 1',10,0.,1.)
myH1.Fill(0.37);
myH1.Fill(0.78);
myH1.Fill(0.51);

c= r.TCanvas('myCanvas');
myH1.Draw();
c.SaveAs('histogram.png')
```

- The following examples creates histogram, fill it and draws is
- Output on the right:



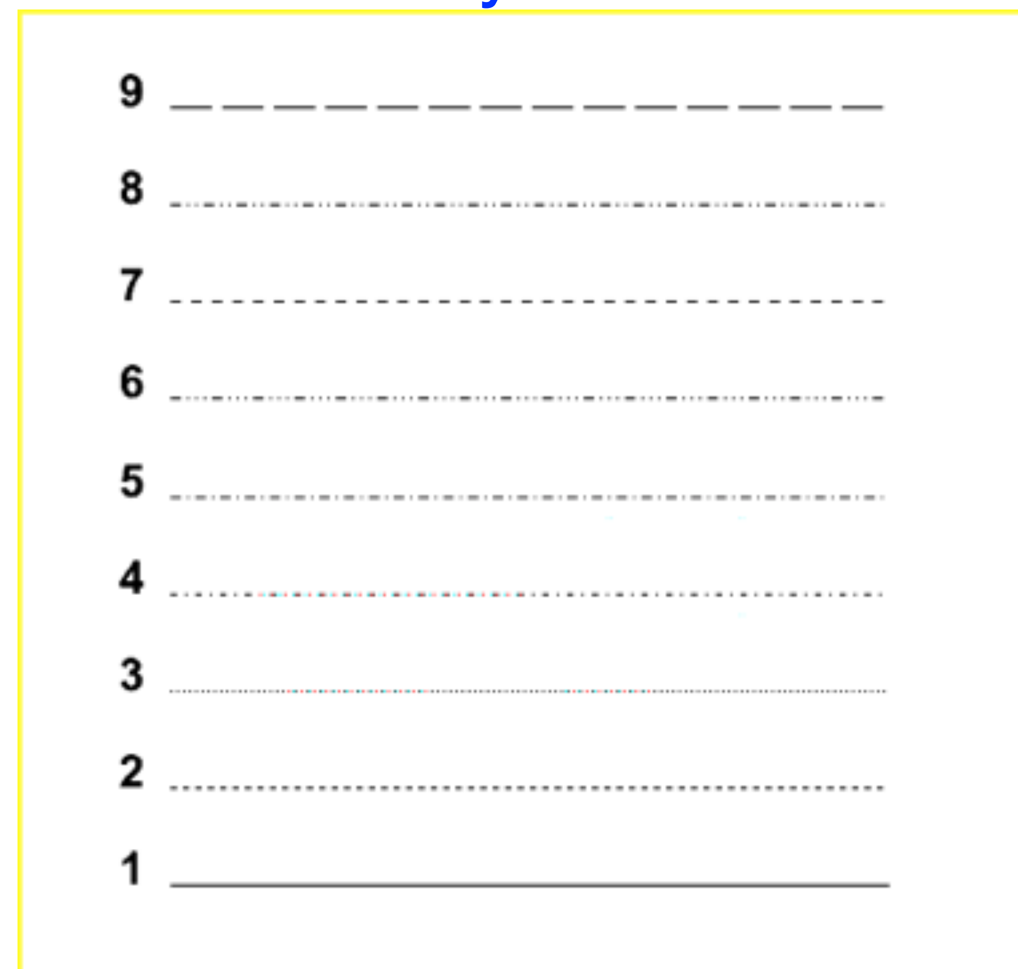
Drawing Options

- There are many arguments associated with `Draw()`. The most important are the following, more in the root manual
  - "`E`" draw the error bars
  - "`SAME`" overlay an already drawn histo with another one
  - "`C`" connect the data points with a smooth curvature
- most options can be combined, e.g.: "`SAME,E`" "`SAMEE`" respectively
- Many options are common for several ROOT objects, e.g. mathematical functions TF1
- other useful methods for histograms are:
  - `myH1.SetLineColor(4)`
  - `myH1.SetLineWidth(3)`
  - `myH1.SetFillColor(2)`
  - `myH1.SetFillStyle(3005)`
  - `myH1.SetLineStyle(2)`

Styleguide

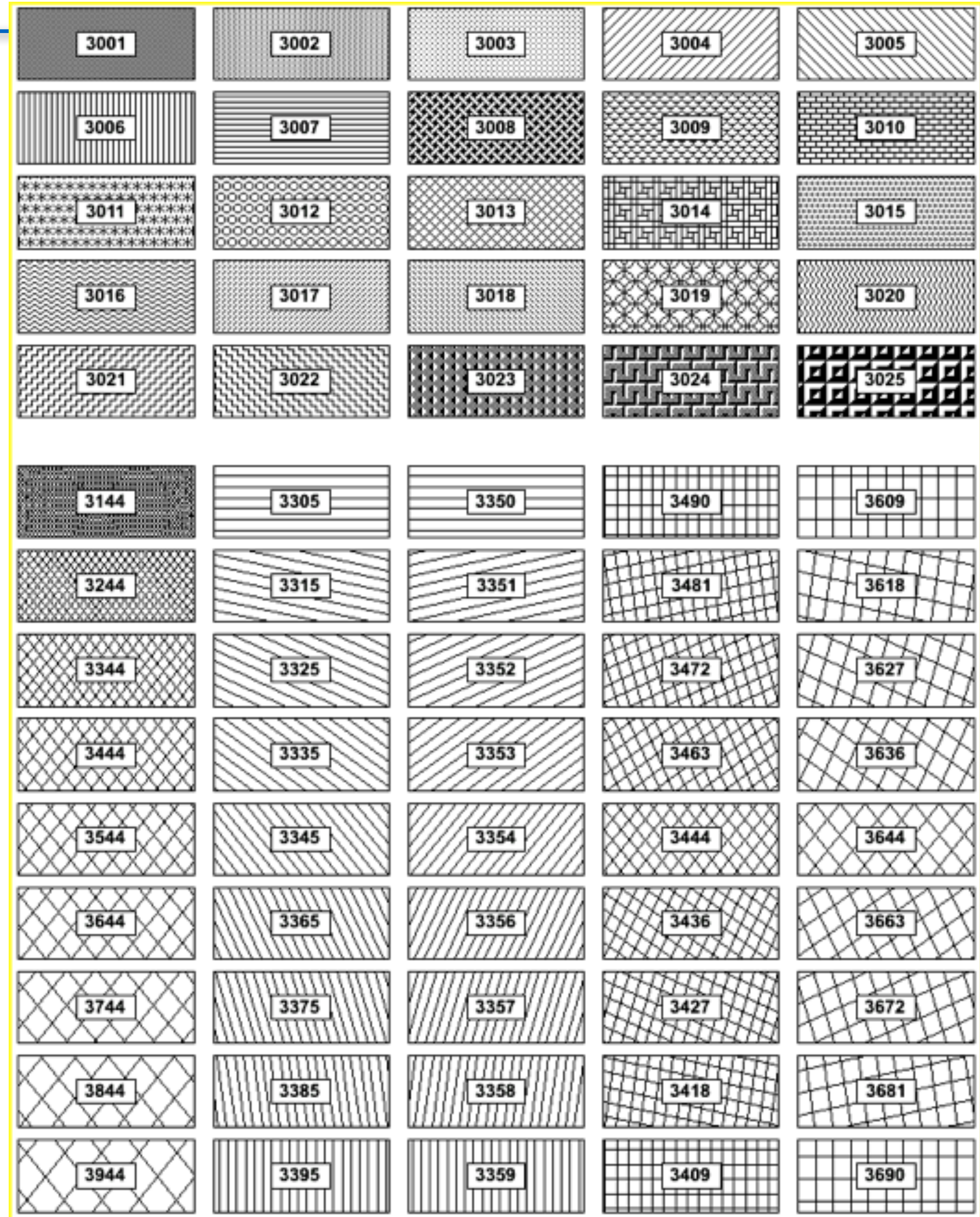
colors

line styles



marker styles

Fill Patterns

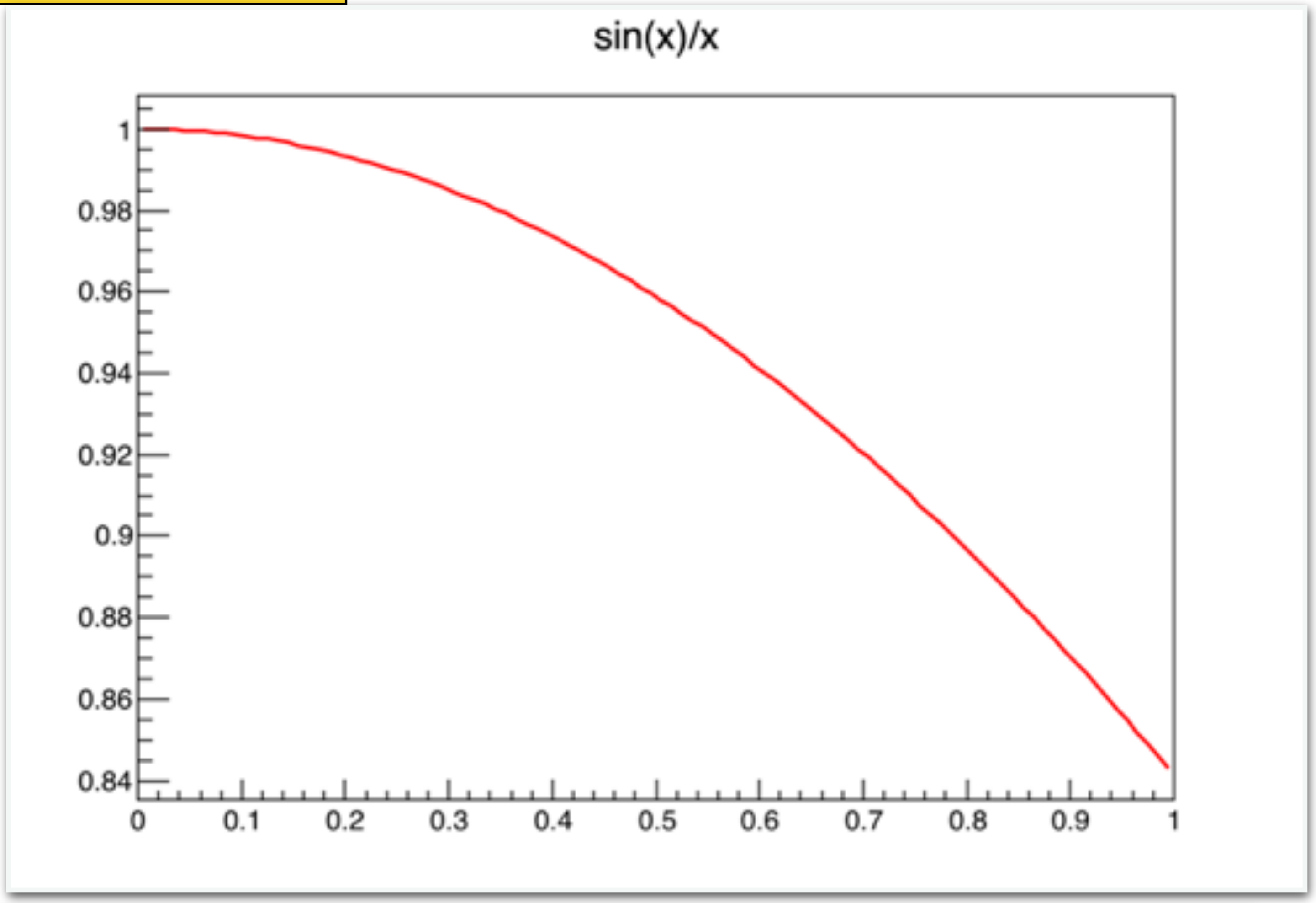


function.py

- `ROOT` is able to display mathematical functions and graphs as well. The following macros draws the function `sin(x)/x` within a range of 0 to 1

```
import ROOT as r

myFunc = r.TF1("myFunction","sin(x)/x",0.,1.)
c= r.TCanvas(‘myCanvas')
myFunc.Draw()
c.SaveAs('function.png')
```

name function range



- `TF1` are useful to fit parameters

TFunction Options

- There are many functions predefined in TMath. Those are particularly useful for fitting, a small selection:
  - `pol1, pol2, pol3....`
  - `gaus`
  - `Landau`
  - `BreitWigner`
  - `sin, cos, ...`
  - `sqrt`
  - `exp`
  - `log`
  - `...`
- Functions can be combined with each other whereas the number of parameters and initial parameters can be chosen (almost) freely. More information regarding this can be found here:

  http://root.cern.ch/root/html402/TFormula.html

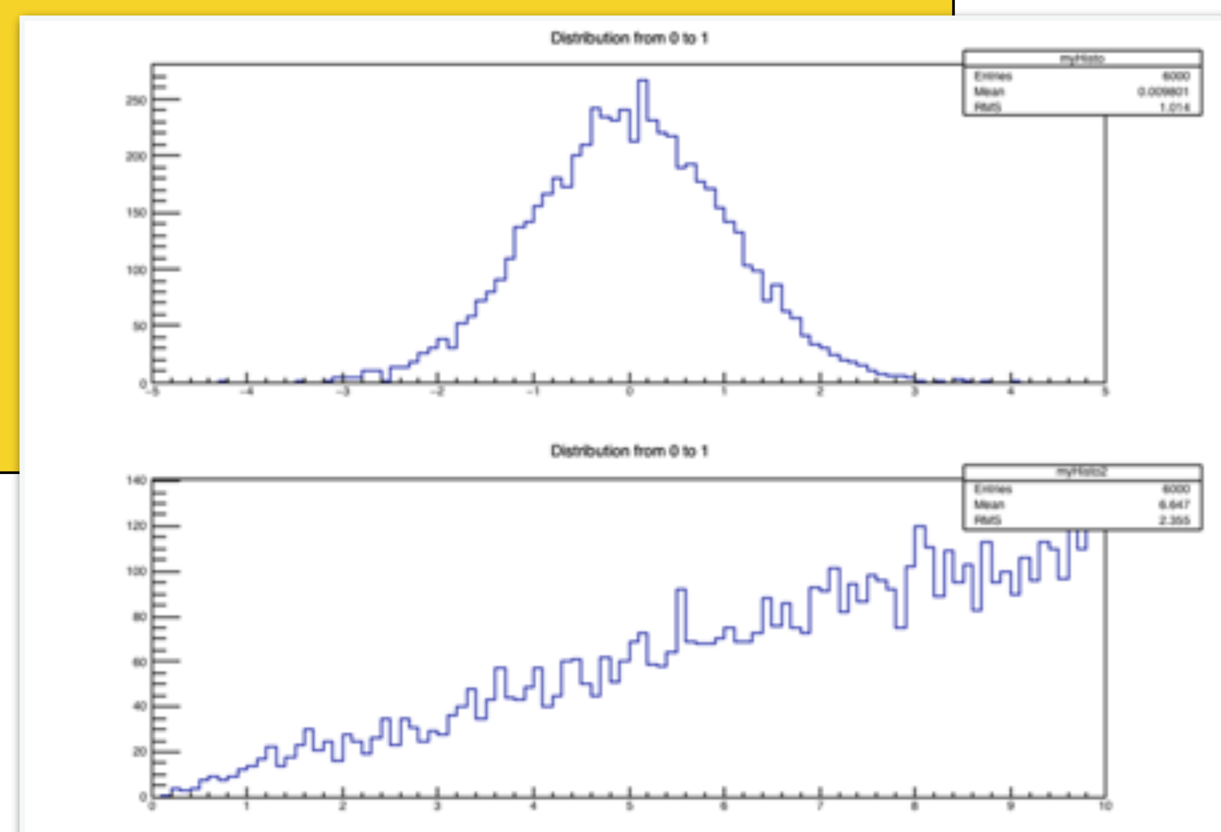
histogram2.py

- The `Canvas` represents the windows on which histograms and graphs are drawn. Calling `Draw()` automatically creates a canvas. Creating a canvas manually allows to apply various changes, e.g. drawing separate histograms, adjusting ist size, saving etc.

```
import ROOT as r

myH1 = r.TH1F('myHisto','Distribution from 0 to 1’,100,-5.,5.)
myH1.FillRandom('gaus',6000)
myH2 = r.TH1F('myHisto2','Distribution from 0 to 1',100,0.,10.)
f1=r.TF1('f1','2*x',0,10)
myH2.FillRandom('f1',6000)
c= r.TCanvas('myCanvas')
c.Divide(1,2)
c.cd(1)
myH1.Draw()
c.cd(2)
myH2.Draw()
c.SaveAs('histogram2.png')
```

split canvas in 1 column, 2 lines

select 1st and 2nd subcanvas



fit.py

- This examples illustrates how to perform a fit to data using the `Fit()` function. To do so an appropriate function within a sensible range has to be used.

```
import ROOT as r

myH1 = r.TH1F('myHisto','gaussian distribution 1',100,-5.,5.)
myGaus = r.TF1('myGaus','gaus',-5,5)
myH1.FillRandom('gaus',6000)
myH1.SetMarkerColor(2)
myH1.SetMarkerStyle(20)
myH1.Fit('myGaus')
c= r.TCanvas('myCanvas');
myH1.Draw('E')
c.SaveAs('fit.png')
print ' --------------------------------'
print ' chi2/dof: ' + str( myGaus.GetChisquare()/myGaus.GetNDF() )
print ' mean: ' + str( myGaus.GetParameter(1) ) +'+/-' +
str( myGaus.GetParError(1) )
print ' width: ' + str( myGaus.GetParameter(2) ) + '+/- ' +
str(myGaus.GetParError(2) )
```

fit range

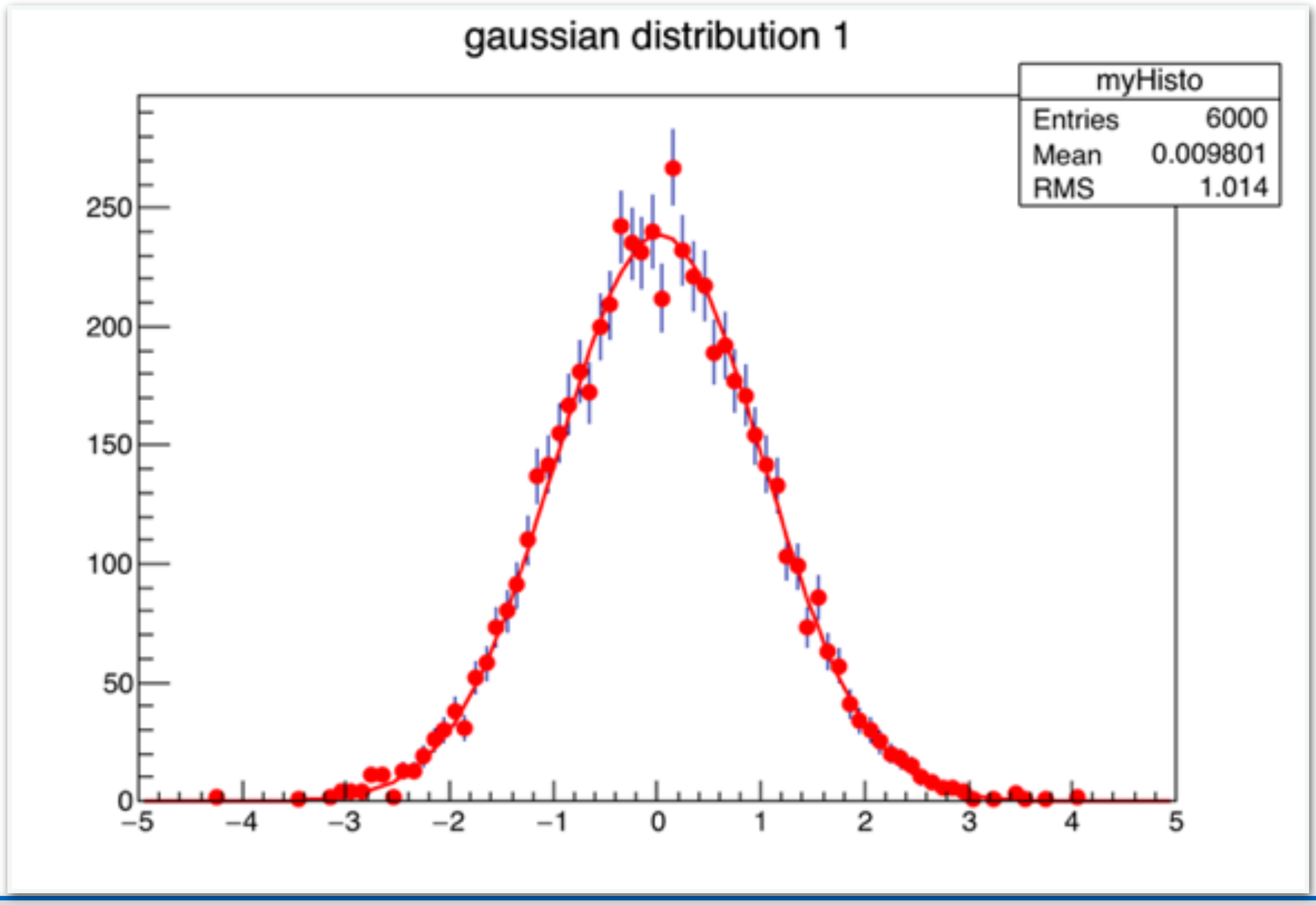
change marker & color

draw only data points with error bars

print fit parameters and fit quality

Output

```
Info in <TCanvas::MakeDefCanvas>:  created default TCanvas with name c1
 FCN=65.2581 FROM MIGRAD    STATUS=CONVERGED      62 CALLS           63 TOTAL
                     EDM=9.11306e-10    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     2.38594e+02   3.80928e+00   1.23098e-02  -6.27631e-06
   2  Mean         2.05919e-02   1.29916e-02   5.15403e-05   2.31062e-03
   3  Sigma        9.93349e-01   9.33666e-03   1.00053e-05   2.46256e-03
Info in <TCanvas::Print>: file fit.png has been created
 --------------------------------
 chi2/dof: 0.974002076002
 mean: 0.0205918892051+/-0.0129916016934
 width: 0.993349327318+/- 0.00933665930944
```



saveHisto.py

- Another useful tool is saving histograms to files and retrieving them again. In order to do so we have to use the TFile object:

```
TFile* file=new TFile("file.root", "RECREATE")
```

file name

if file exists it will be re-created

- ROOT stores the object in the last TFile object which has been accessed (use `cd()` to change there if necessary)

```
myH1.Draw()
```

- One has to close the file properly before exiting the program:

```
file.Close()
```

```
import ROOT as r

myH1 = r.TH1F('myHisto','Distribution from 0 to 1',100,-5.,5.)
file=r.TFile('histo.root','RECREATE')
myH1.FillRandom('gaus',6000)
myH1.Draw()
myH1.Write()
file.Close()
```

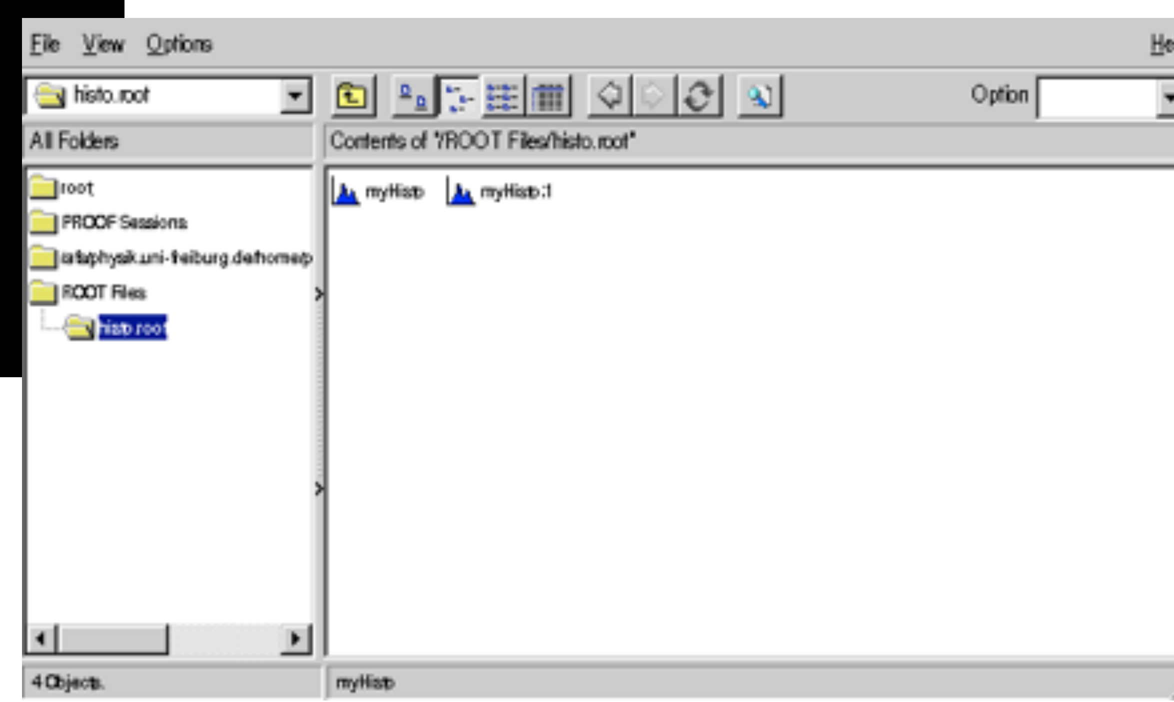
TBrowser

- Objects in `ROOT` files can be either read manually using the `TBrowser` or by using a script and reuse them.
- The `TBrowser` is an interactive browser for `ROOT` objects.
- To open the file in a simple `ROOT` session it's most easy to pass the file name as argument when calling the shell command:

```
#>root filename.root
```

```
penning@haco05:~fp/root/myprogs>root histo.root
root [0]
Attaching file histo.root as _file0...
root [1] new TBrowser
(class TBrowser*)0x8cd8950
```

starting TBrowser



getHisto.py

- It's often easier to load an object into a macro and use it later again.

```
import ROOT as r

file = r.TFile('histo.root','OPEN')
myH1 = file.Get('myHisto')
c= r.TCanvas('myCanvas')
myH1.Draw()
c.SaveAs('getHisto.png')
```

- The procedure, consisting of `TObject.Write()`

  and `File.get('myHisto')`

  can can be used for many ROOT objects, (TF1, TH1, Canvas, etc).

readFile.py

- Read in data from a text file like this:

```
import ROOT as r

nlines=0
histo = r.TH1F('_histo','Peaks', 1250, 0., 1250 )
c = r.TCanvas('myCanvas')

for line in open('peaks.dat'):
    nlines=nlines+1
    elems = line.split()
    histo.SetBinContent( nlines, int(elems[0]) )

print 'found '+str(nlines)+' data points'
histo.Draw()
c.SaveAs('readFile.png')
```

open the file

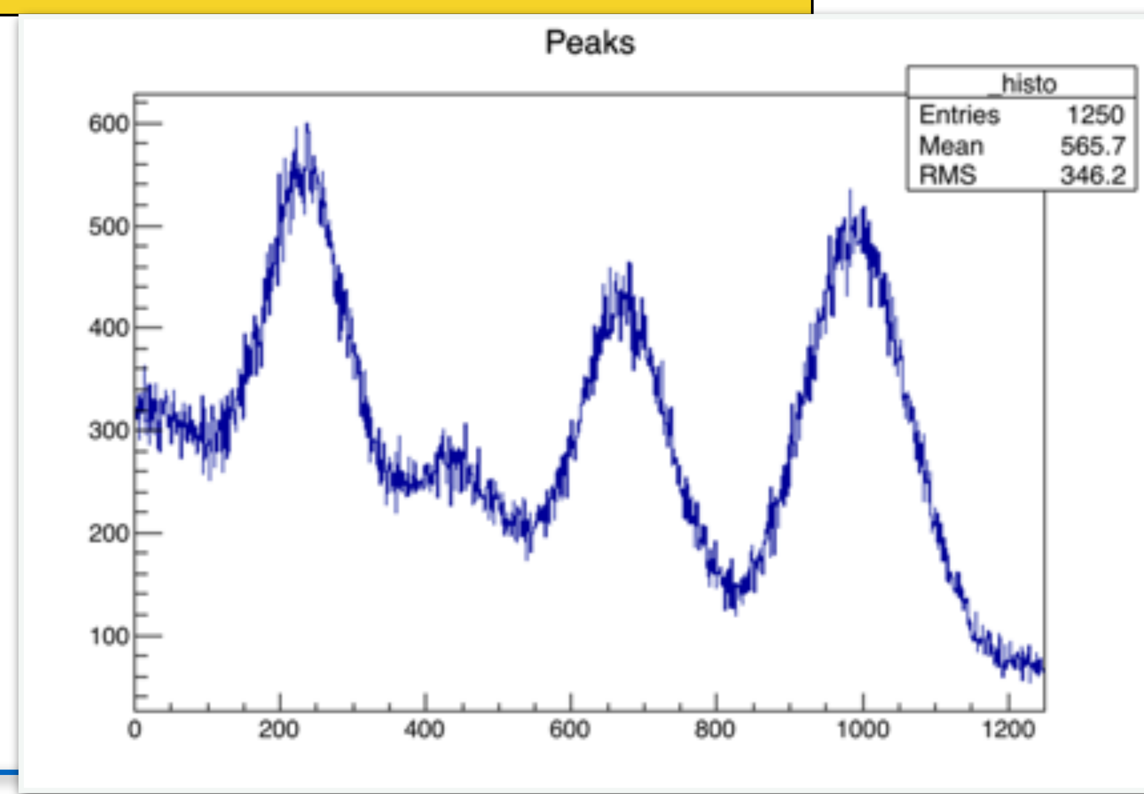
split line into its elements

filling histogram, each line i corresponds to bin i

Input file:

```
322
323
322
312
314
335
291
331
329
...
```

Output:



University of BRISTOL

More Fitting

- In the next example we are going to fit a Gaussian peak on top of an falling background. We will used a combination of Gaussian and the linear function to fit this examples

```
fitFunc = r.TF1("fitFunc","pol1(0)+gaus(2)",0,300)
```

- Here

```
pol(0)+gaus(2) =
[0]+[1]*x+[2]*exp(-0.5*((x-[3])/[4])**2)
```

$$= \quad a + b \cdot x \cdot + c \cdot e^{-0.5\left(\frac{x-d}{e}\right)^2}$$

- In the expression "`pol1(0)+gaus(2)`" `(0)` resp. `(2)` correspond to the variables of the formula
- Useful functions:
  - `func.SetParameter(indices,value);`
  - `func.SetParLimits(indice, lower_boundary,  upper_boundary);`
  - `r.gStyle.SetOptFit();`

fit2.py

```
import ROOT as r

nlines=0
histo = r.TH1F('histo','Peaks', 350, 0., 350 )
c= r.TCanvas('myCanvas')

for line in open('peak.dat'):
    nlines=nlines+1
    elems = line.split()
    histo.SetBinContent( int(elems[0]), int(elems[1]) )

print 'found '+str(nlines)+' data points'
fitFunc = r.TF1('fitFunc','pol1(0)+gaus(2)',0,300)
fitFunc.SetParameter(3,175)
fitFunc.SetParameter(4,20)

r.gStyle.SetOptFit()
histo.Rebin(3)
histo.Fit('fitFunc')
histo.Draw('E')
c.SaveAs('fit2.png')
```

set value of bin x_i directly

set meaningful initial value of mean and width of the Gaussian

display fit parameters in statistics box

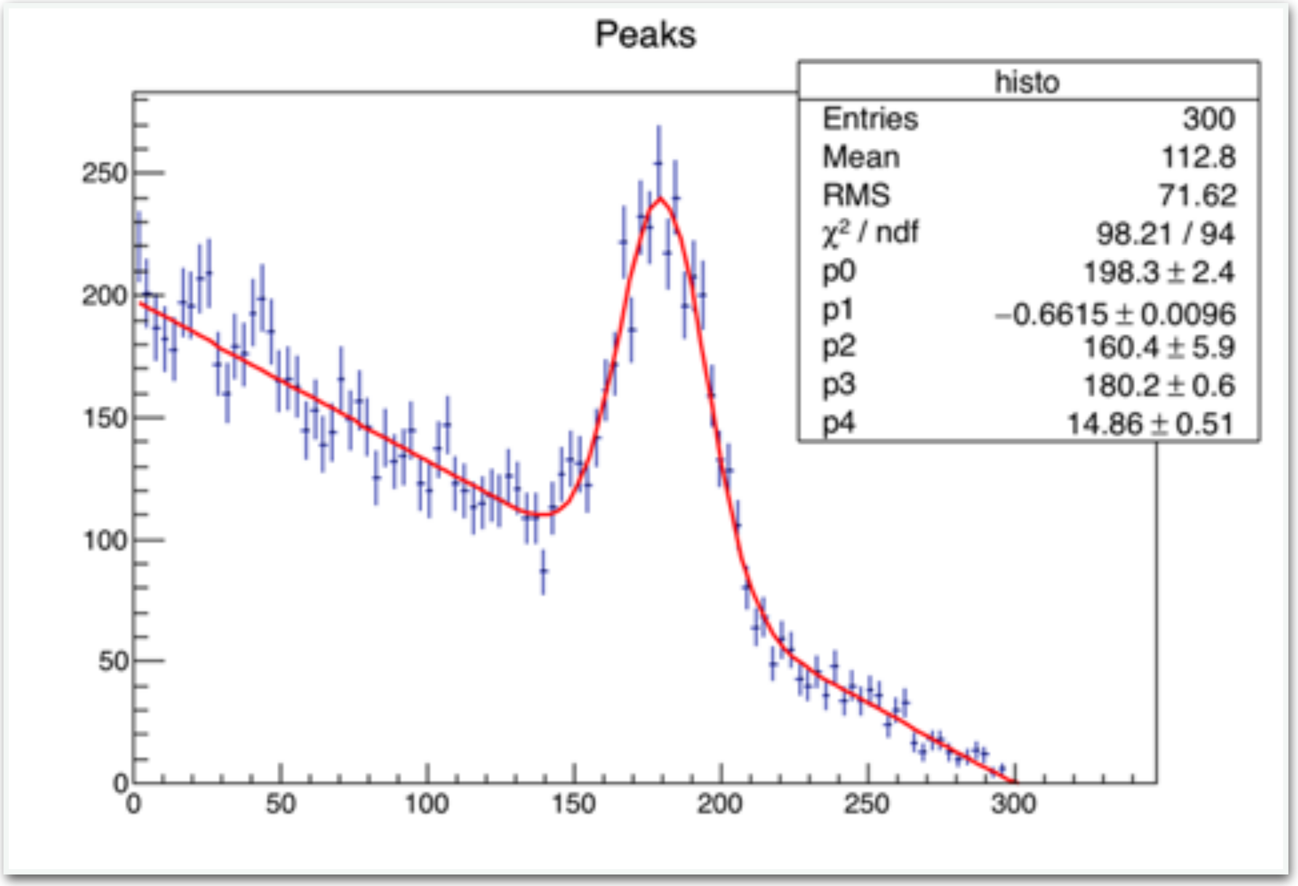
change binning of histogram

fit2.py

- Input file contains now two columns:

```
0    0
1    63
2    79
3    78
4    66
5    65
6    70
7    70
...
```

- Result:



linRegression.py

- Ge the covariance matrix as follows:

```
fitter = r.TVirtualFitter.GetFitter()
matrix = r.TMatrixD(2,2, fitter.GetCovarianceMatrix())
matrix.Print()
```

access the fitter object

access the cov. matrix

dim. of matrix

- One has to pass the correct dimensions when initializing the matrix:
- (n x n), n = number of fit parameter

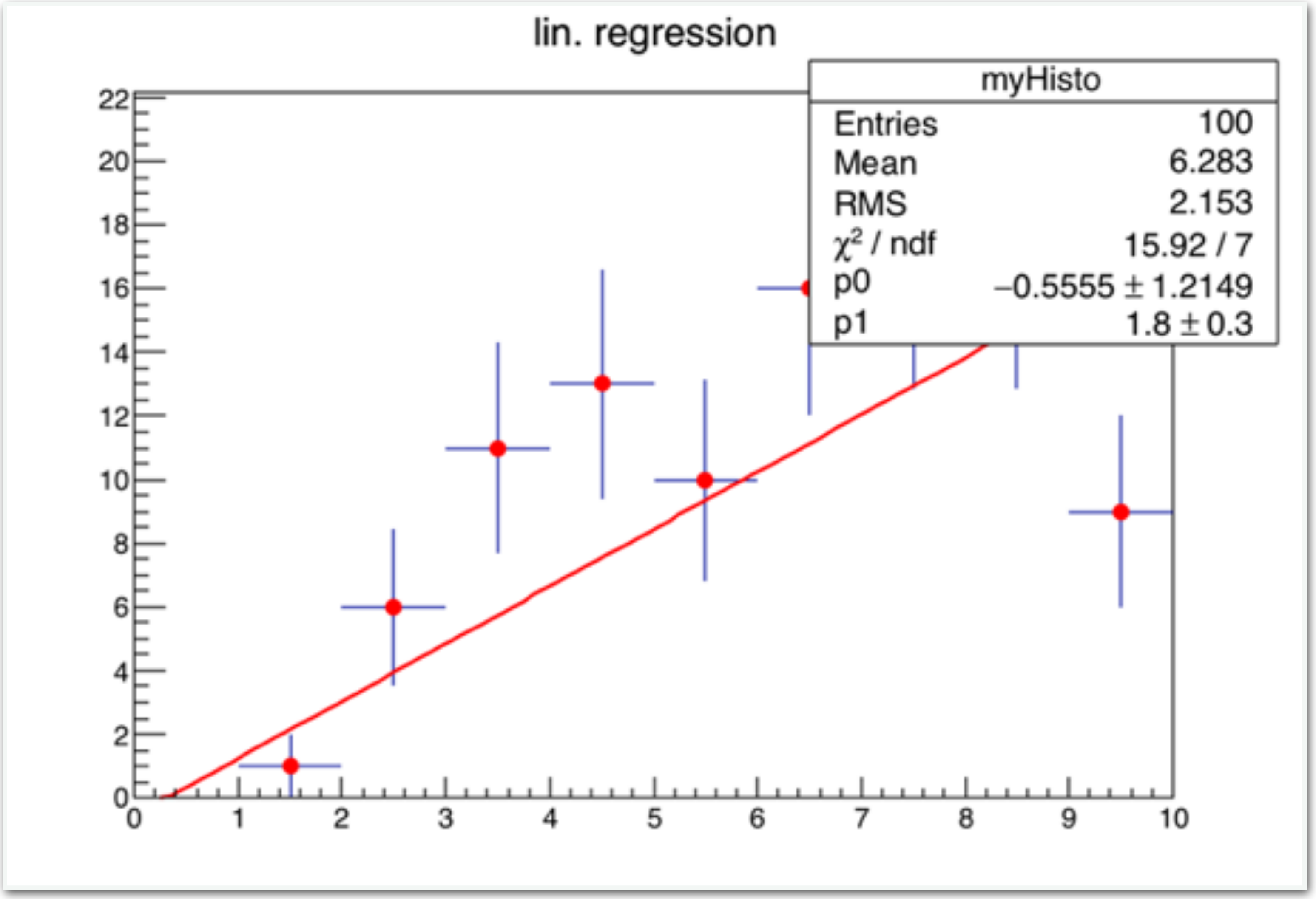
```
import ROOT as r

r.gStyle.SetOptFit()
myH1 = r.TH1F('myHisto','lin. regression',10,0.,10.)
myPol1 = r.TF1('myPol1','2*x',0.,10.)
myH1.FillRandom('myPol1',100)
myH1.SetMarkerColor(2)
myH1.SetMarkerStyle(20)
myH1.Fit('pol1')
c= r.TCanvas('myCanvas')
myH1.Draw('E')
c.SaveAs('linRegression.png')

fitter = r.TVirtualFitter.GetFitter()
matrix = r.TMatrixD(2,2, fitter.GetCovarianceMatrix())
matrix.Print()
```

fit with polynomial of 1st order, e.g. lin. regression

linRegression.py

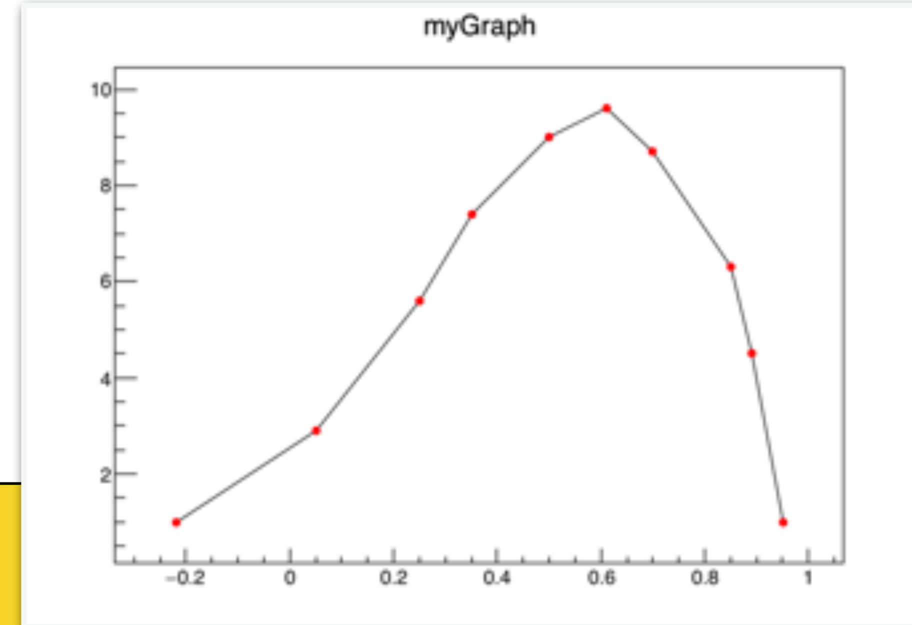
- Output:

```
****************************************
Minimizer is Linear
Chi2                      =       15.922
NDf                       =            7
p0                        =      -0.5555    +/-    1.21491
p1                        =      1.79955    +/-    0.295277
Info in <TCanvas::Print>: file linRegression.png has been created

2x2 matrix is as follows

     |      0      |      1      |
-------------------------------
   0 |      1.476       -0.2796
   1 |    -0.2796       0.08719
```



Graph.py

- `TGraphs` are useful to create draws from set of coordinates
- `Draw()` options:
  - “a“ draw axis
  - “p“ draw marker
  - “l“ connect with line




```
import ROOT as r
import array

r.gStyle.SetOptFit()

x  = [-0.22, 0.05, 0.25, 0.35, 0.5, 0.61,0.7,0.85,0.89,0.95]
y  = [1,2.9,5.6,7.4,9,9.6,8.7,6.3,4.5,1]
xv = array.array('d', x)
yv = array.array('d', y)
myGraph = r.TGraph(len(x), xv, yv)
myGraph.SetTitle('myGraph')
myGraph.SetMarkerColor(2)
myGraph.SetMarkerStyle(20)
myGraph.SetMarkerSize(0.7)
c= r.TCanvas('myCanvas')
myGraph.Draw('apl')
c.SaveAs('graph.png')
```

data rows x, y

convert python list to ‘double’ (‘d’) array

Define graph with n data points

Set marker color, size and style

Draw axis, marker dots and connect with a line

grapherrors.py

```
import ROOT as r
import array
r.gStyle.SetOptFit()

x  = [-0.22, 0.05, 0.25, 0.35, 0.5, 0.61,0.7,0.85,0.89,0.95]
y  = [1,2.9,5.6,7.4,9,9.6,8.7,6.3,4.5,1]
ex = [.05,.1,.07,.07,.04,.05,.06,.07,.08,.05]
ey = [.8,.7,.6,.5,.4,.4,.5,.6,.7,.8]
xv = array.array('d', x)
yv = array.array('d', y)
exv = array.array('d', ex)
eyv = array.array('d', ey)
myGraph = r.TGraphErrors(len(x),xv,yv,exv,eyv)
c= r.TCanvas('myCanvas')
myGraph.Draw("ap")
func = r.TF1("func","[0]+[1]*x+[2]*pow(x,2)+[3]*pow(x,3)",-0.3,1.)
func.SetParameter(0,1)
func.SetParameter(1,1)
func.SetParameter(2,1)
func.SetParameter(3,-10)
func.SetLineColor(4)

myGraph.Fit(func,"R")
myGraph.SetMaximum(13)
myGraph.GetHistogram().SetXTitle("X-Axis")
myGraph.GetHistogram().SetYTitle("Y-Axis")
c.SaveAs('grapherrors.png')
```

x, y data

x, y uncertainties

convert to arrays

Graph with n data points & error

define polynomial of 3rd order

set initial values

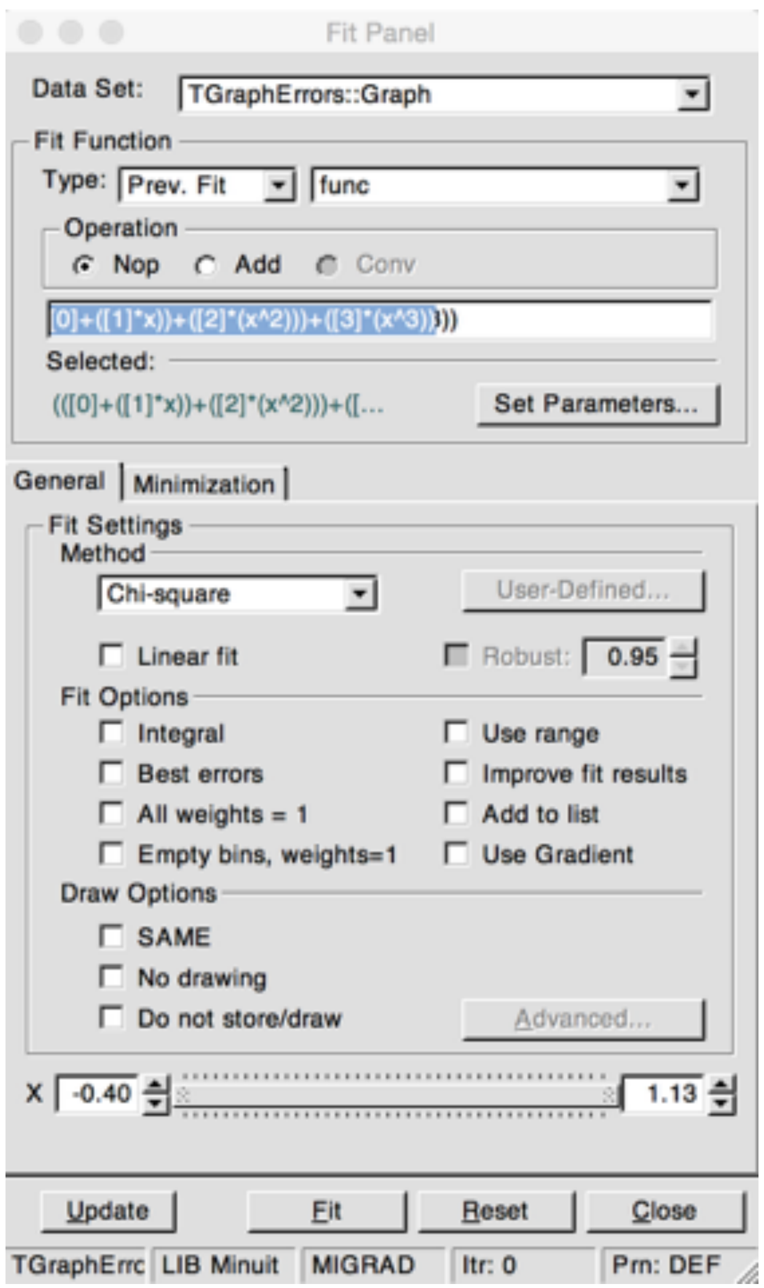
fit, “R“: only within [-0.3,1.0]

maximum of y-axis

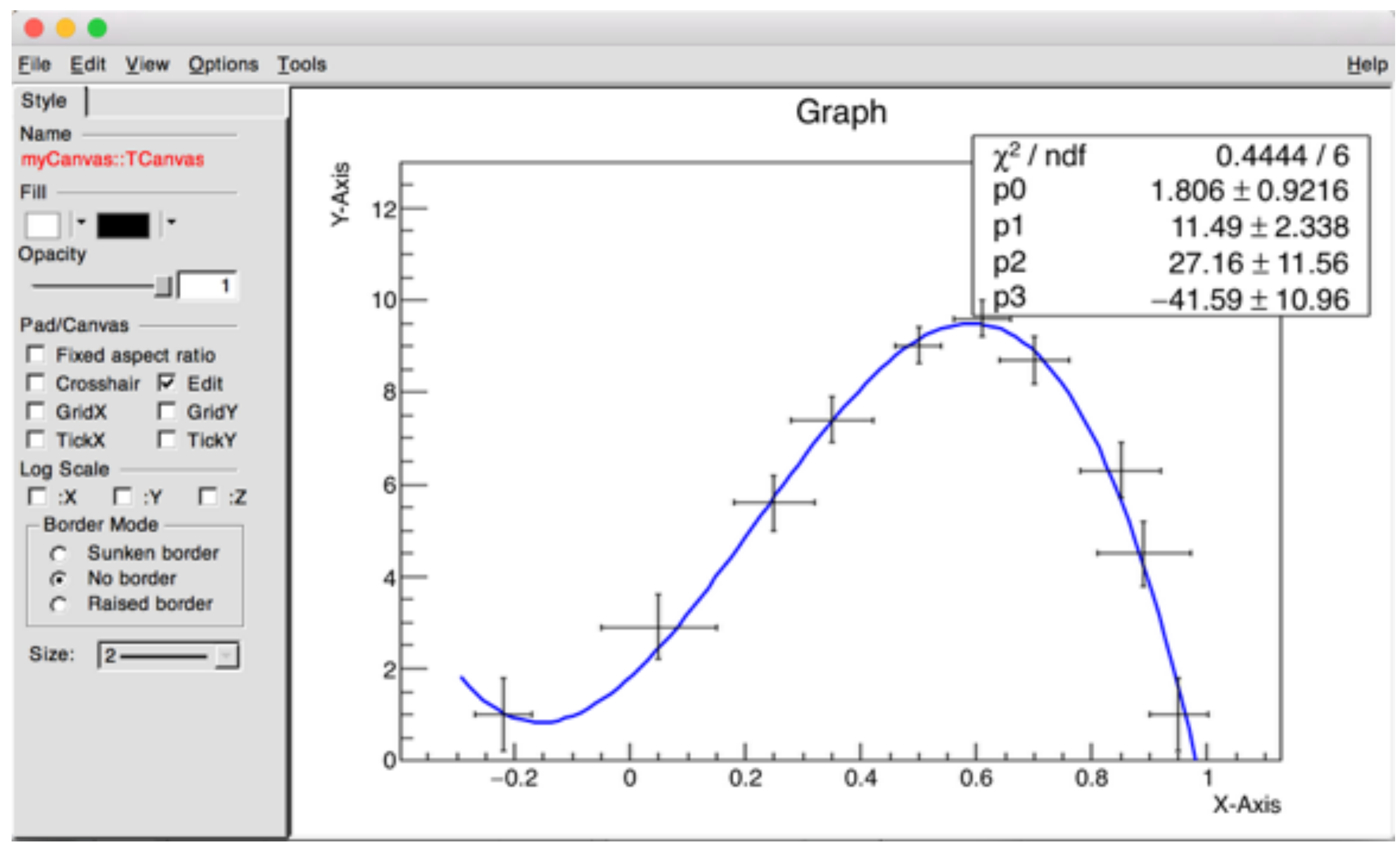
axis labels

grapherrors.py

- Execute with ‘`python -i grapherrors.py`’
- Many operations be modified interactively by selecting and ‘right click’ of the object and choose some action… e.g. change fit and draw options.



- Useful trick: Saving then your canvas manually as ‘`.C`’ file allows to extract the changed options manually and use them in your program.



View → Editor allows to change e.g. Canvas

‘Tools → Fit Panel’ allows to rerun fit

Drawing Options

- ROOT offers the possibility to define 2 dimensional histograms. A 2d histogram, function resp. is defined as:

  - `myH2 = r.TH2F(“my2Dhisto”,”2d histo”,100,0.,1.,100,.0.,1.)`

  - `myFunc2 = r.TF2(“my2Dfunc”,”2d func”,”x^2+y^2”,-1.,1.,-1.,1.)`

- The `Draw()` method for 2d histos and functions offers many additional options, either in a planar or 3D view:
  - 2D: `“BOX”, “COL”, “COLZ”, “TEXT”, “CONT0”, “CONT1”, “CONT2”, “CONT3”, “CONT4”`

  - 3D: `“LEGO”, “LEGO1”, “LEGO2”, “SURF”, “SURF1”, “SURF2”, “SURF3”, “SURF4”`

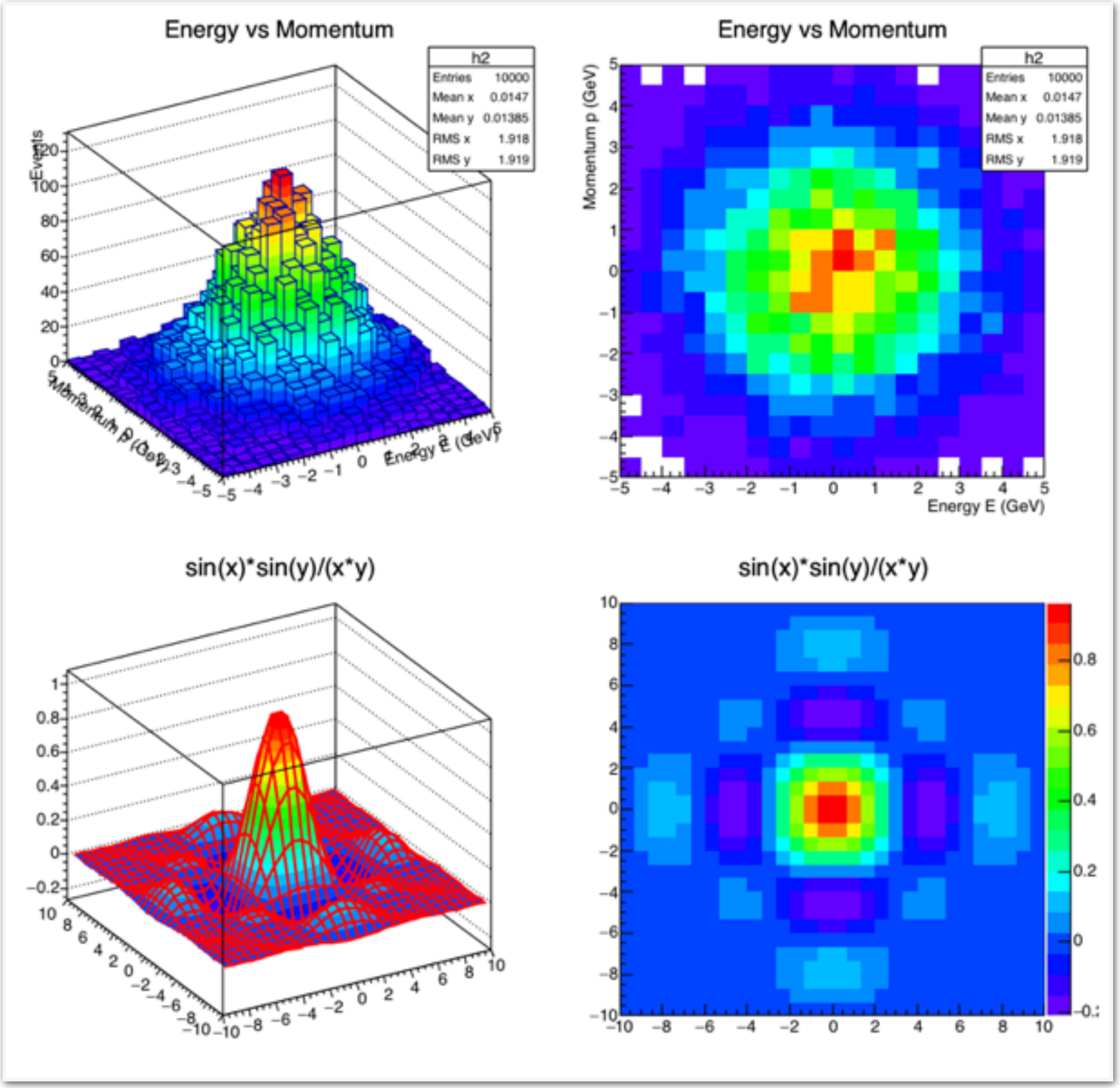
2d_histos.py

- Let's put things together:

```
import ROOT as r

c= r.TCanvas('c1', 'multiple plots', 800, 800)
c.Divide(2,2)
h2 = r.TH2F('h2','Energy vs Momentum',20,-5.,5.,20,-5.,5.)
xygaus = r.TF2("xygaus","xygaus",0,10,0,10)
xygaus.SetParameters(1,0,2,0,2)  #amplitude, meanx,sigmax,meany,sigmay
h2.FillRandom('xygaus',10000)
h2.GetXaxis().SetTitle('Energy E (GeV)')
h2.GetYaxis().SetTitle('Momentum p (GeV)')
h2.GetZaxis().SetTitle('Events')
f2= r.TF2('func2','sin(x)*sin(y)/(x*y)',-10.,10.,-10.,10.)
c.cd(1)
h2.Draw('LEGO2')
c.cd(2)
h2.Draw('COL')
c.cd(3)
f2.Draw('SURF1')
c.cd(3)
f2.Draw('SURF1')
c.cd(4)
f2.Draw('COLZ')
c.SaveAs('2d_histos.png')
```

2d_histos.py

- Output:



Summary

- This tutorial enables you to start doing analysis
- Keep in mind I am not a python expert
- Example code: (including c++ code in subdir)
  - https://dl.dropboxusercontent.com/u/1882892/example_code_py.tar.gz
- Python allows to start programming quickly, but it is slow for resource intensive tasks
- Let me know if there are problems