ROOT TUTORIAL

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https://desycloud.desy.de/index.php/s/RZgiy5fkHjtd5rf

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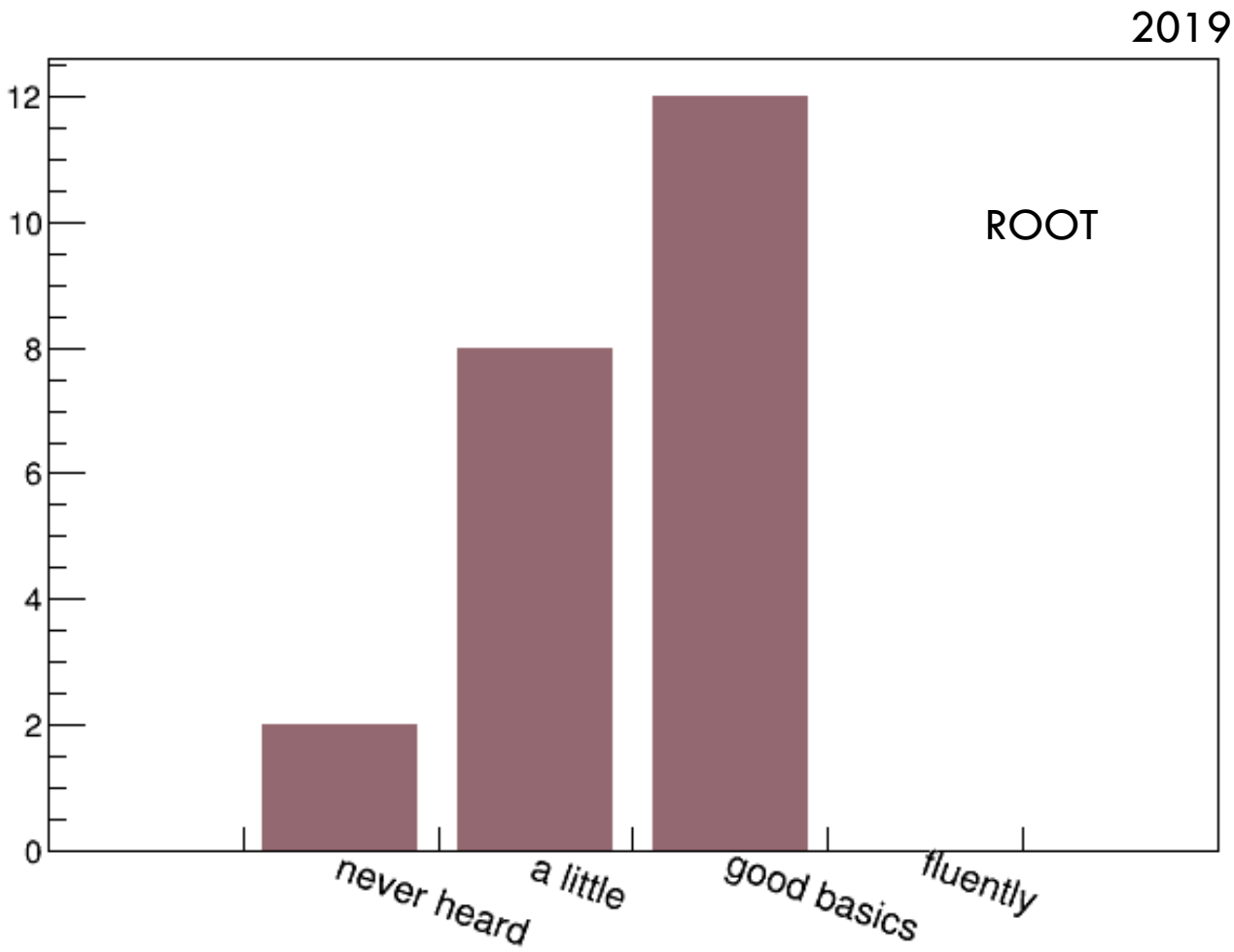
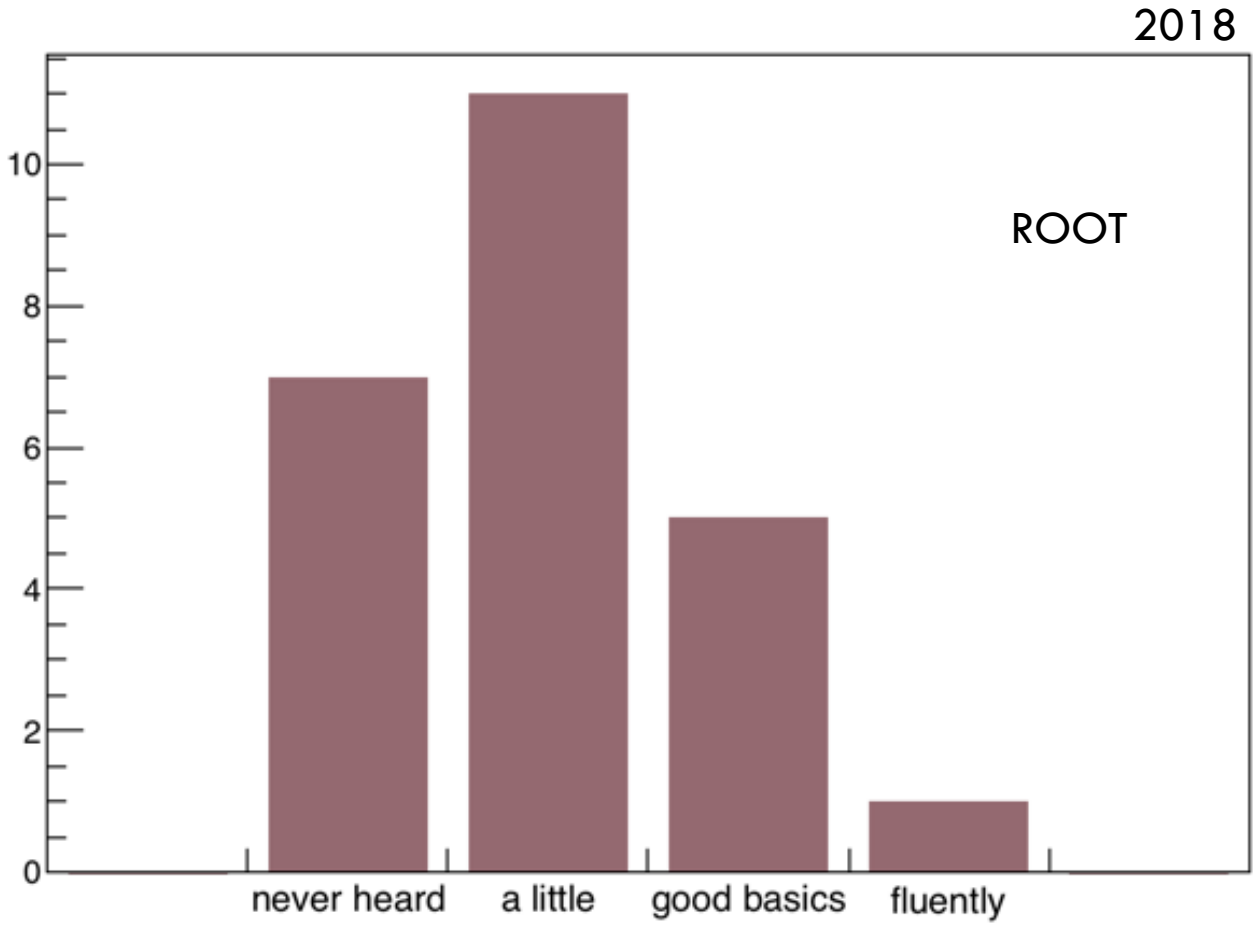
DESY Summer Student Program 2019

Questionnaire on ROOT Experience

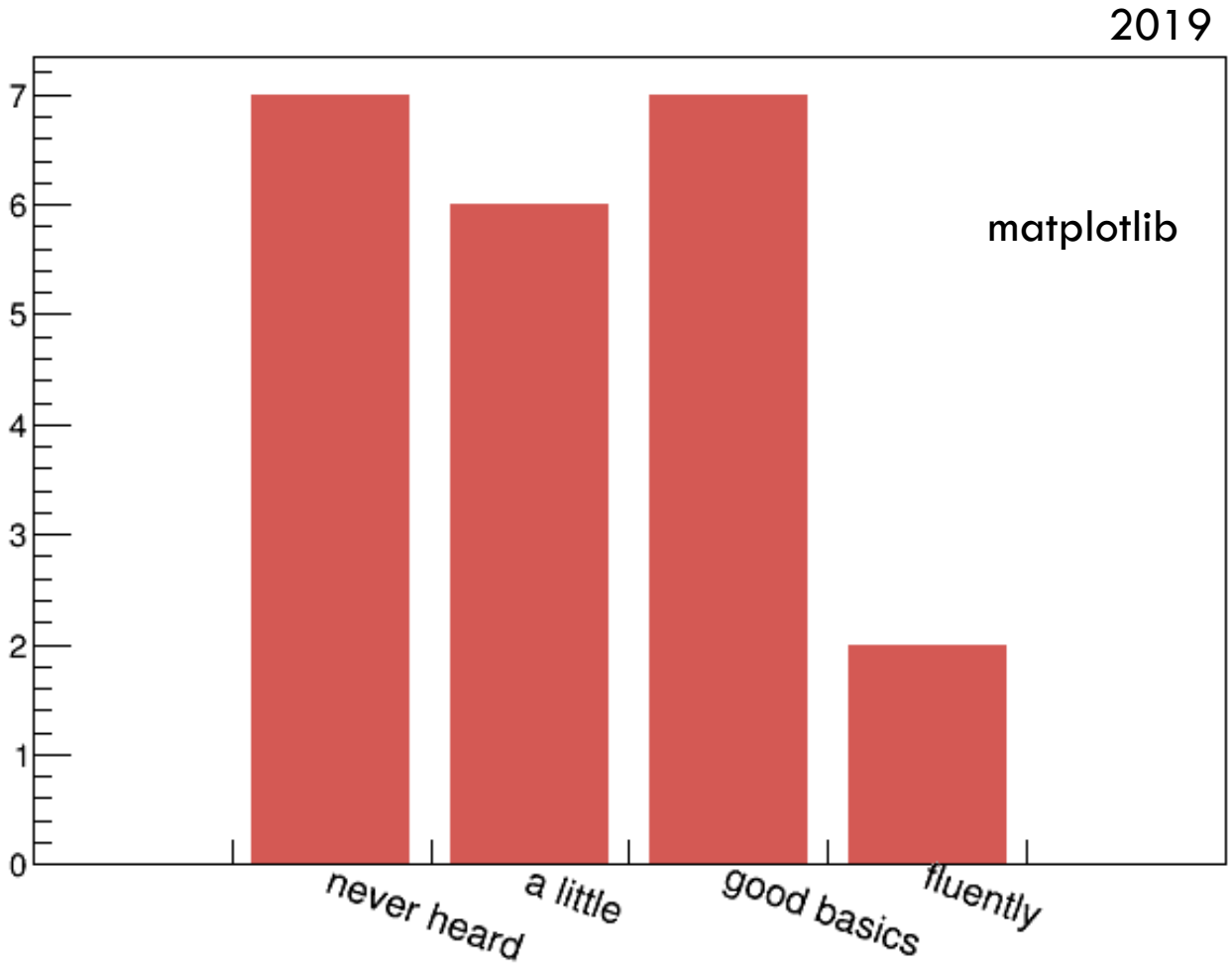


You are good!

Questionnaire on ROOT Experience

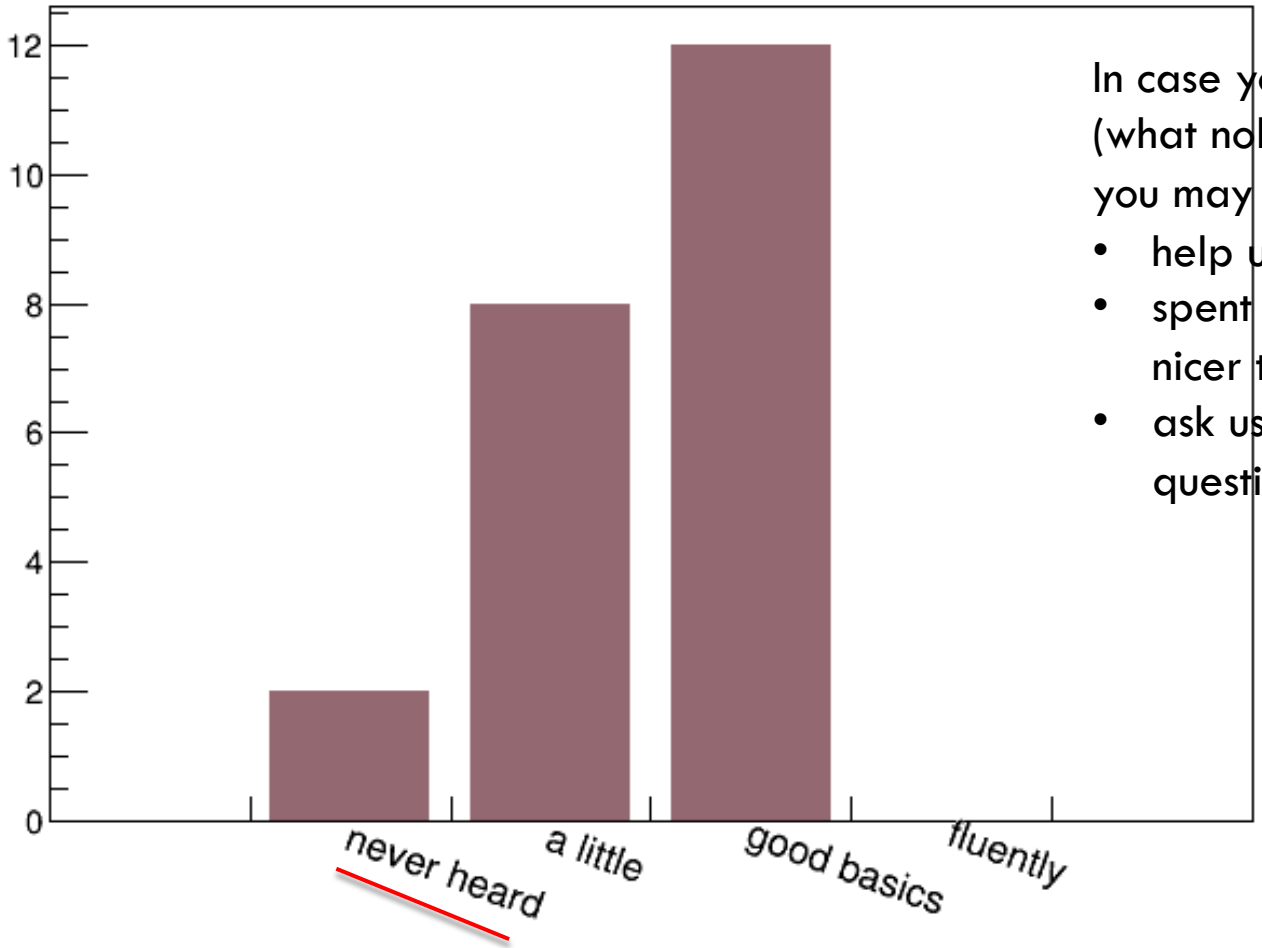


Questionnaire on MatplotLib Experience



Popular in
data science
e.g. deep learning

Questionnaire on ROOT Experience



We will be very basic to get everybody on board.

In case you are really fluent (what nobody claimed this year) you may

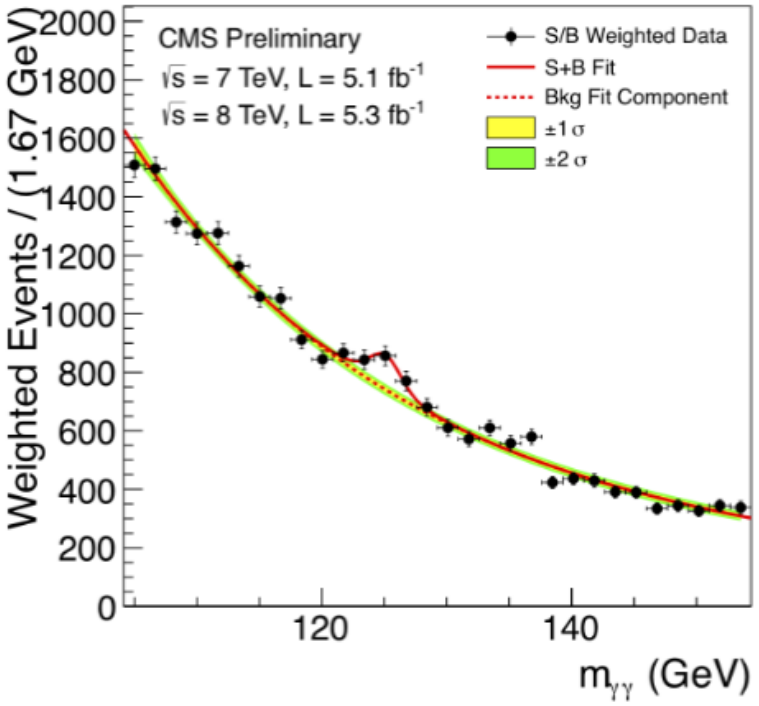
- help us in the exercises or
- spent the afternoons with nicer things
- ask us advanced ROOT questions during the exercises

What is ROOT?

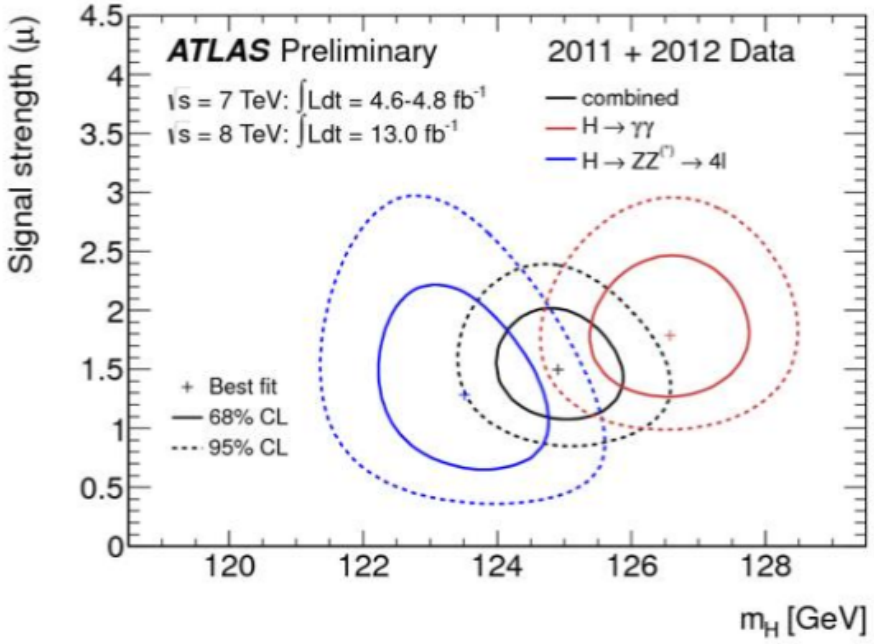
- ROOT is the **Swiss Army Knife of High Energy Physics**
- It will be with you for the rest of your scientific career in HEP

What is ROOT

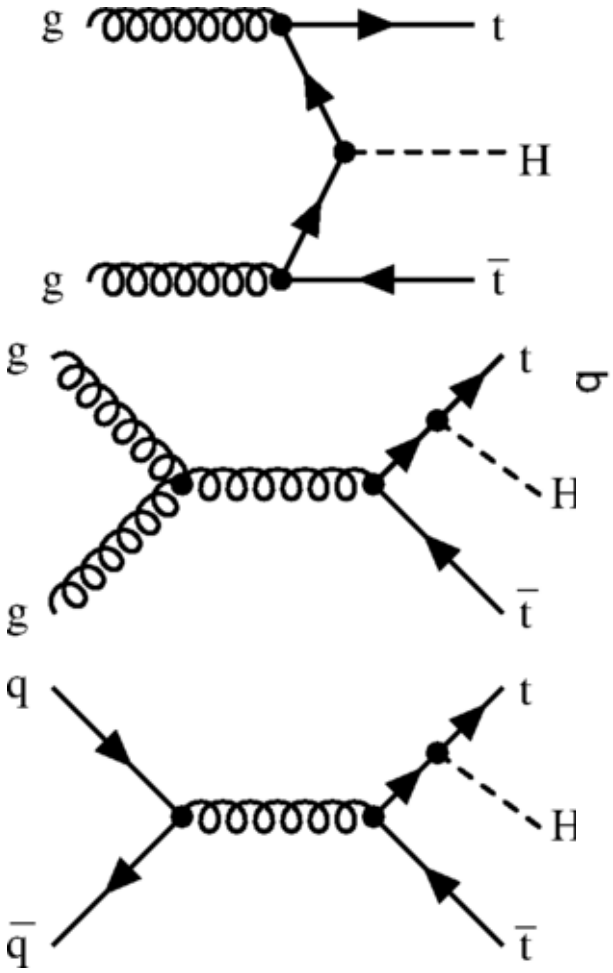
- **Plots:** The Higgs has been "discovered" in a ROOT plot (2012)

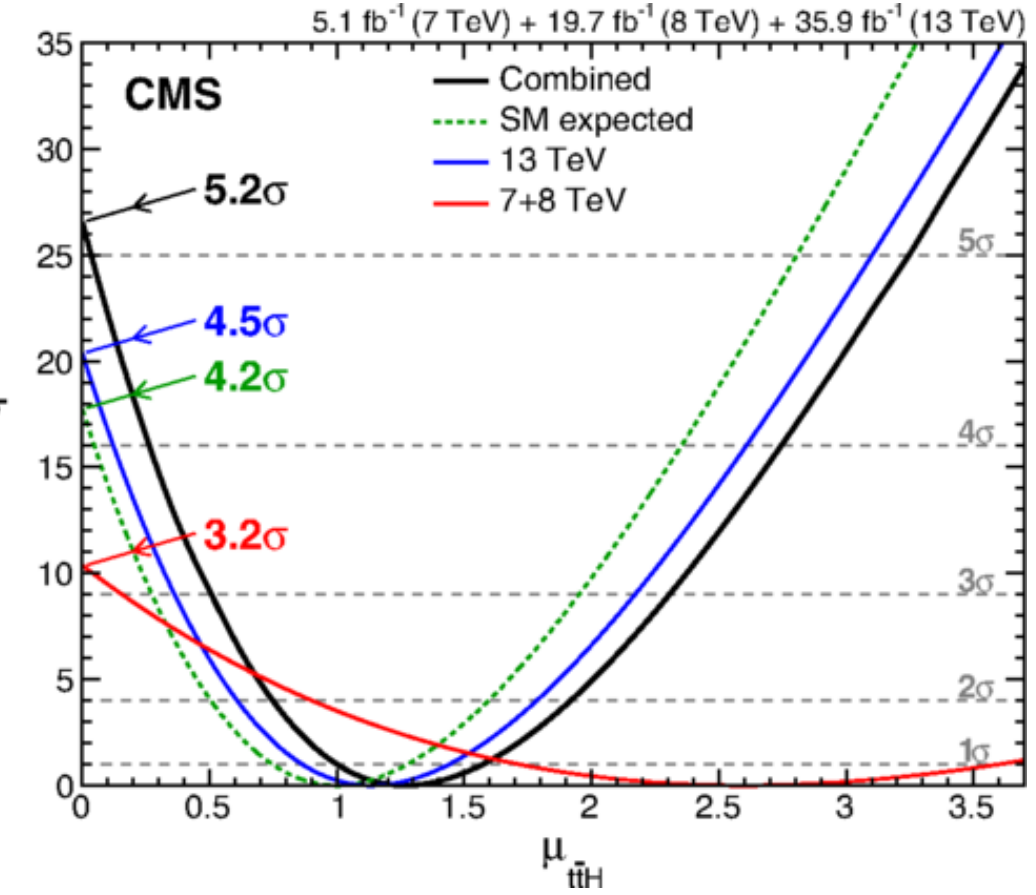


LHC collision in CMS:
event display, also done with ROOT!



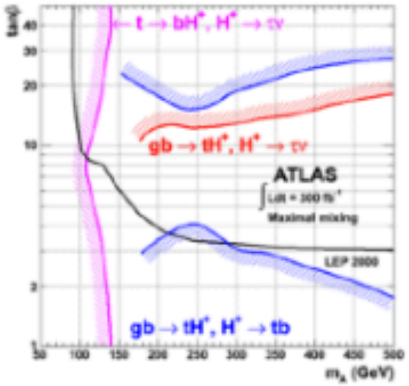
Observation of ttH by CMS and ATLAS 2018 - another ROOT Plot

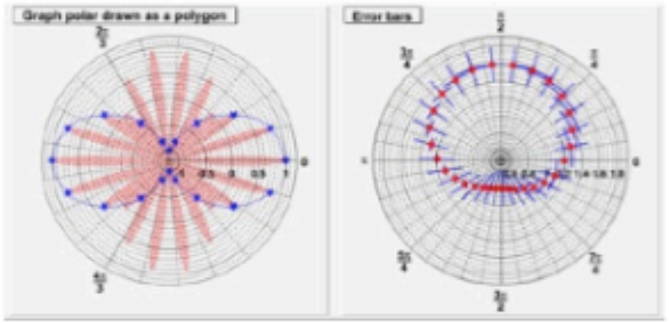


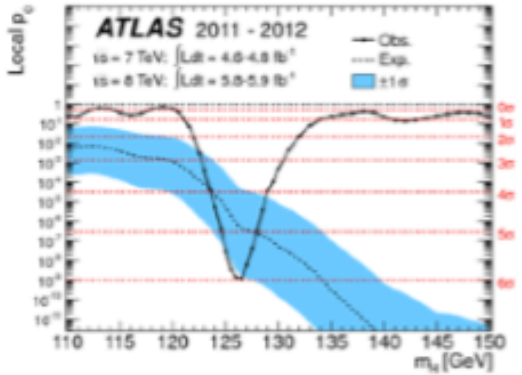


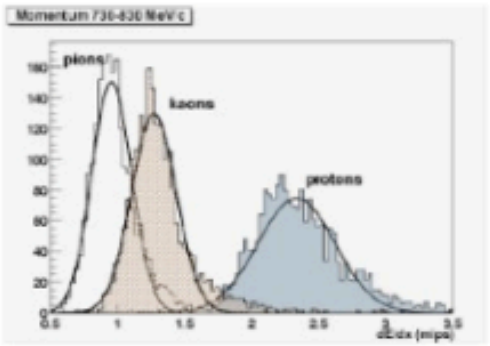
What is ROOT

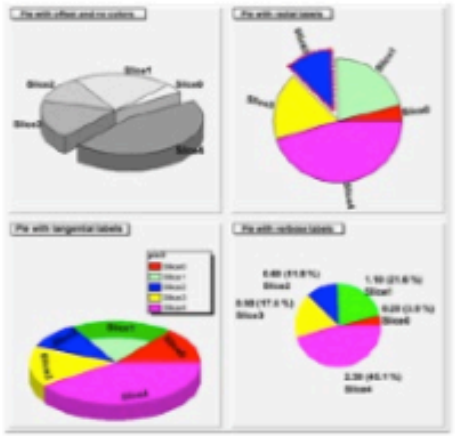
Many formats for data analysis, and not only, plots

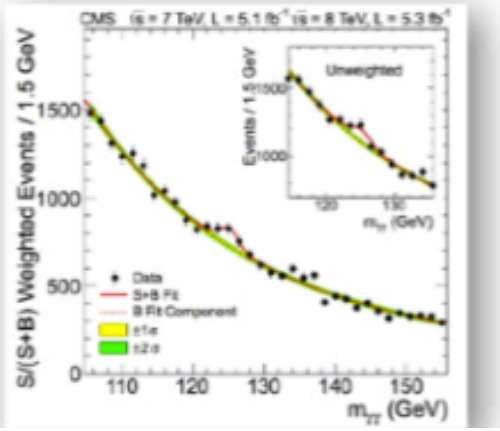






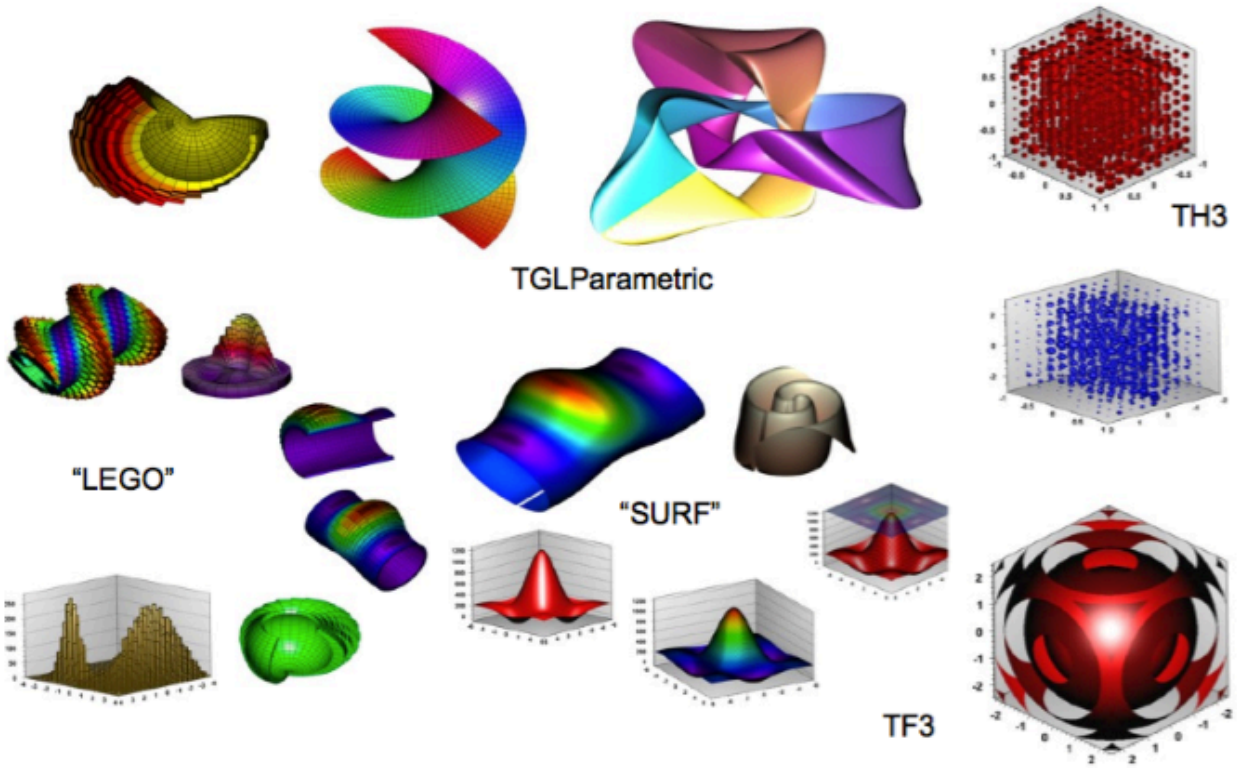






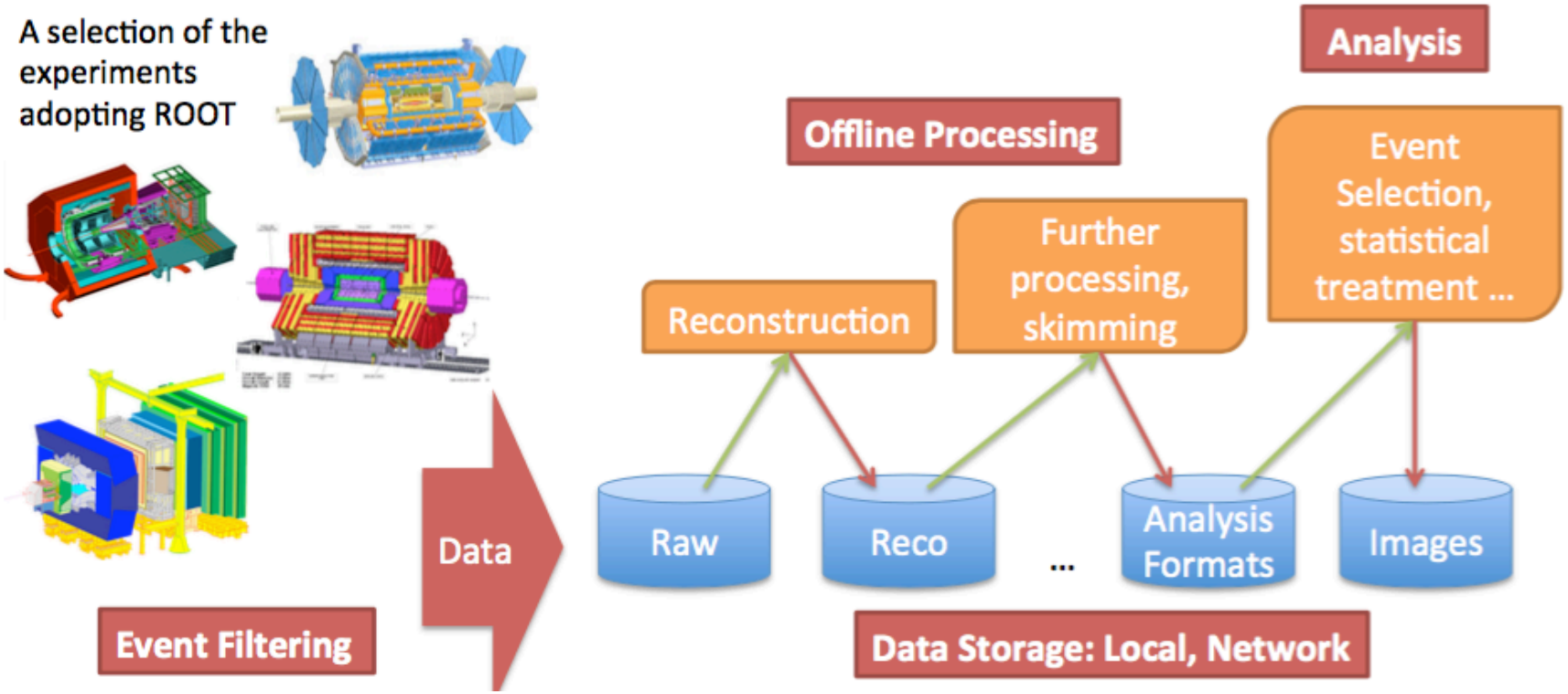
What is ROOT

- more plots in 3D



What is ROOT

- **Data format** for the LHC (and other) experiments

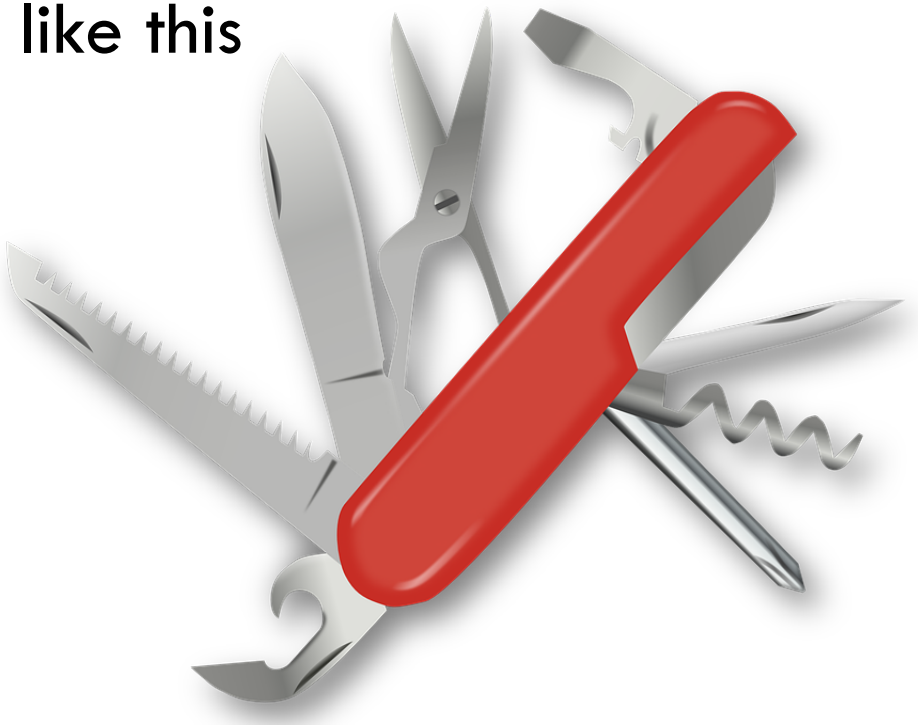


ROOT

- ROOT is an analysis software that is used extensively in particle physics
- The three main aspects are:
  - **Graphics**/Plotting
    - Various 1-dim up to n-dim histogram formats
    - Graphs and functions
  - **Data analysis**
    - Math libraries
    - Statistical libraries such as RooFit/RooStat
    - ML: TMVA (neural network, boosted decision trees, etc.)
  - **Data storage**
    - Data structures for event-based data analysis
- C++14 and python (PyRoot) can both be used

What is ROOT?

- ROOT is the **Swiss Army Knife of High Energy Physics**
- BUT it does not looks like this



What is ROOT

- ROOT is the **Swiss Army Knife of High Energy Physics**
- BUT it does not looks like this

But like this (after 25y of development)

- We try to help you to take your first steps into the ROOT Jungle

Some technical details

- **Connect to your DESY account**
  (or install ROOT on your notebook)
- Code examples throughout the talk with colors

```
Execute this
```

```
Some example code
```

- WG server depending on your group CMS/Belle/ILC/**?**
  - ssh -Y naf-cms.desy.de
  - ssh -Y naf-belle.desy.de
  - ssh -Y naf-ilc.desy.de
- Setup the needed software on a DESY machine

```
module load gcc/47
module load python/2.7
module load root6
```

The version is a bit old 6.02.00 but this does not matter here.

everytime you login
or put into: **.zshrc**
or **.bashrc**

Installation on your laptop

Installation (maybe) for later
Here, we will use the NAF!

- **Installation**
  - A recent version of ROOT 6 can be obtained from (**2019-06-25**)
    https://root.cern.ch/content/release-61800
    as binaries for Linux, Windows and Mac OS X
    and as source code.
- **Mac** root_v6.18.00.macosx64-10.14-clang100.dmg
- **Linux - Ubuntu**
  - Ready-to-use packages of ROOT are available for Ubuntu and other distros.
- **Windows**
  - root_v6.18.00.win32.vc16..exe
  - In addition, you would need Python:
    https://www.python.org/downloads/
  - **Better** use an X11 server e.g. **MobaXterm**
    and login on a **DESY Linux server**
- **Web interface:** https://nafhh-x2.desy.de:3443/auth/ssh (xfce)

Get Connected

- Everybody ready to start a ROOT session ????
  - It's a hands-on introduction!
  - Login
  - load the modules
  - start ROOT by typing `root`

Crash Course in OO Programming

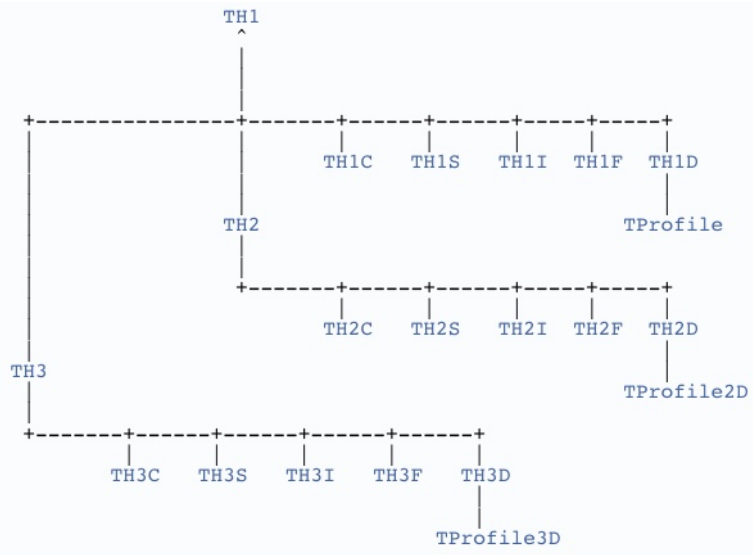
- A program is a list of commands
- A function=subroutine=method is an encapsulated list of commands

```
def Example(x):
  x2 = x*x
  return x2
```
Python

```
double Example(double x){
  double x2 = x*x;
  return x2;
}
```
C++

- **class=object** is a combination of data and operations
  operation=function=method
- Classes can be part of a hierarchy ⟹ Object-Oriented Programming = OOP
  - **Inheritance**

solve a problem only once and re-use the code



Crash Course in OO Programming

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```
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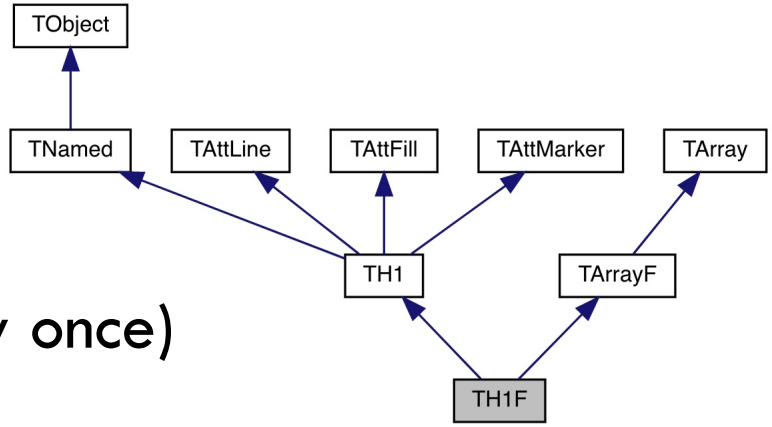
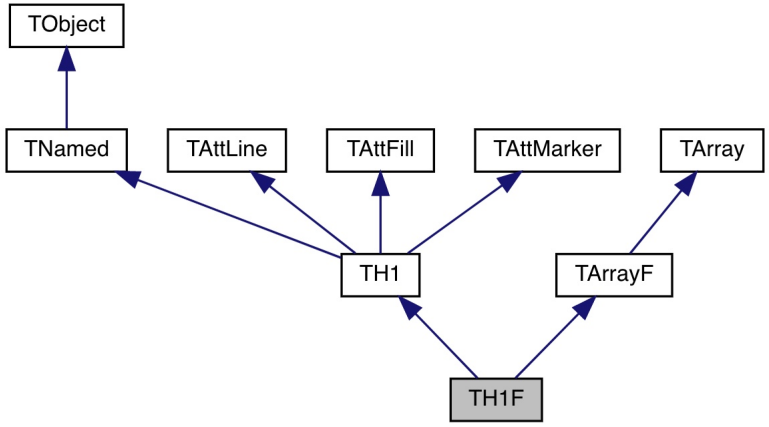
- **class=object** is a combination of data and operations
  operation=function=method
- Classes can be part of a hierarchy ⟹ Object-Oriented Programming = OOP
  - **Multiple Inheritance** (define only once)



Crash Course in OO Programming

- Data and function are called **members**
- There are ways to restrict access to class members in arbitrary (confusing) complex way
- Members can be hidden (**private** or **protected**) to the outside or accessible for everybody (**public**)
- protected members are
- But **friend classes** can access members



Getting started with ROOT: C++

- ROOT interface is prompt based and speaks C++

```
$ root -l
root [0] gROOT->GetVersion()
(const char *) "6.02/05"
root [1] sqrt(9) + 4
(const double)7.0000000000000000e+00
```

- Quit the root session

```
root [5] .q
```

- External macros

```
root [2] .x Example.C(2)
```

or

```
root [3] .L Example.C
root [4] Example(2)
```

Create Example.C

```
float Example(float x) {
  float x2 = x*x;
  return x2;
}
```

From command line (quotation marks needed if function takes argument):

```
$ root –l –q "Example.C(2)"
```

-b batch i.e. no display

Getting started with ROOT: C++

- In ROOT everything is a class
  - Either a variable or a pointer

```
$ root –l
root [0] TH1F h("h","A histogram",100,-5,5)
(TH1F &) Name: h Title: A histogram NbinsX: 100
```

TH1F is the histogram class
(A 1D histogram of floats)
"h" is the unique internal name you give it as a reference
"A histogram" a title that will be be used for drawing
100,-5,5 number of bins lower/upper edge

  - Functionality is implemented by methods

```
root [1] h.FillRandom("gaus")
root [2] h.Draw()
```

- TAB completion works!!!

```
root [3] TH1[TAB KEY]
root [3] TH1F::[TAB KEY]
root [3] h.[TAB KEY]
```

```
root [4] .ls
root [5] .undo      // .undo n
root [6] .help
```

  - Tells you which class names exists that start with TH1
  - which methods are implemented in a class

The ROOT home page

- The ultimate reference
  - https://root.cern.ch/
  - https://root.cern.ch/doc/v618/modules.html
- Tons of information, tutorials, guides, …

10 minutes to test the ROOT interface and check the web page

Getting started: PyROOT

- Start the python environment and load ROOT

```
$ python
>>> from ROOT import gROOT,TH1F
>>> gROOT.GetVersion()
'6.02/05'
>>> from math import sqrt
>>> sqrt(9) + 4
7.0
>>> help(TH1F)
…
>>> from Example import *
>>> Example(2)
4
```

- Quit the session

```
>>> quit() (or Ctrl + D)
```

Create Example.py (function)

```
def Example( x ):
    x2 = x*x
    return x2
```

Create Example2.py (plain macro)

```
from ROOT import *
print "Hello World"
for i in range(0,5):
    print i
```

```
$ python -i Example2.py
            or
>>> from Example import *
```

-i keeps the python prompt open

Comparison: Python vs. C++

- Both languages have their pros and cons

Python	C/C++
interpreted	compiled but BUT ROOT comes with an interpreter
slower execution of python code	fast
dynamic typing /checks at runtime	strict type checking at compile time
automatic memory management	partly manual memory management
blocks separated by indentation	code blocks separated by {}

- You can use ROOT in the C++ way or through Python
  - Python is easier for beginners – This is what we do in the exercises
  - ROOT is C++ code
  - Depends on the group you work with – you will need both in HEP

Python

C++


```
#defining a variable
#just use it
a = 1
b = 1.5
#printing things to the screen
print a, "is not equal", b

#importing functions/classes
from ROOT import TH1F

#Indentation defines commands
#loops/statement

#For loop
for i in range(0,10):
    print i
#if/else statements
if b == c:
    print "they are equal"
elif b >  c:
    print "b is bigger"
else:
    print "c is bigger"
```

```
//defining a variable
//declare its type!
int a = 1;
double b = 1.5;
//printing output
cout<<a<<" is not equal "<<b<<endl;

//importing packages
#include "TH1F.h"

//{} define the commands inside
//loops/statement

//For loop
for (int i =0; i < 10; i++){
     cout << i << endl;}
//if/else statements
 if (b == c){
   cout<<"they are equal"<<endl;}
 else if ( b > c){
   cout<<"b is bigger"<<endl;}
 else{
   cout<<"c is bigger"<<endl;}
```

Pointer, Scope and lifetime in C++

- Typical ROOT C++:
  - TH1F* hist = new TH1F("hist","",10,0,10);
    - hist->Draw();
  - TH1F hist("hist","",10,0,10);
    - hist.Draw();
- {int n=3;} cout<<n<<endl; <- Error!
  - variables have a limited scope, they disappear outside their scope, that is { ... }
- Look at ~kruecker/public/sst2019_root/disapearing.C
- What's going wrong here?

ipython: a convenient python shell

- module load gcc/47
- module load python/2.7
- module load root6
- **ipython**
  - History:
    - Unix style: up,down-arrows and search with ^R
  - Extended help:
    - TH1F? TH1F.Fill?
    - help(TH1F)

Basic classes in ROOT

- **TObject:** base class for all ROOT objects
- **TH1**: base class for 1-, 2-, 3-D Histograms
- **TStyle**: class for style of histograms, axis, title, markers, etc…
- **TCanvas**: class for graphical display
- **TGraph**: class of graphic object based on x and y arrays
- **TF1**: base class for functions
- **TFile**: class for reading/writing root files
- **TTree**: basic storage format in ROOT
- **TMath**: class for math routines
- **TRandom3**: random generator class
- **TBrowser:** browse your files

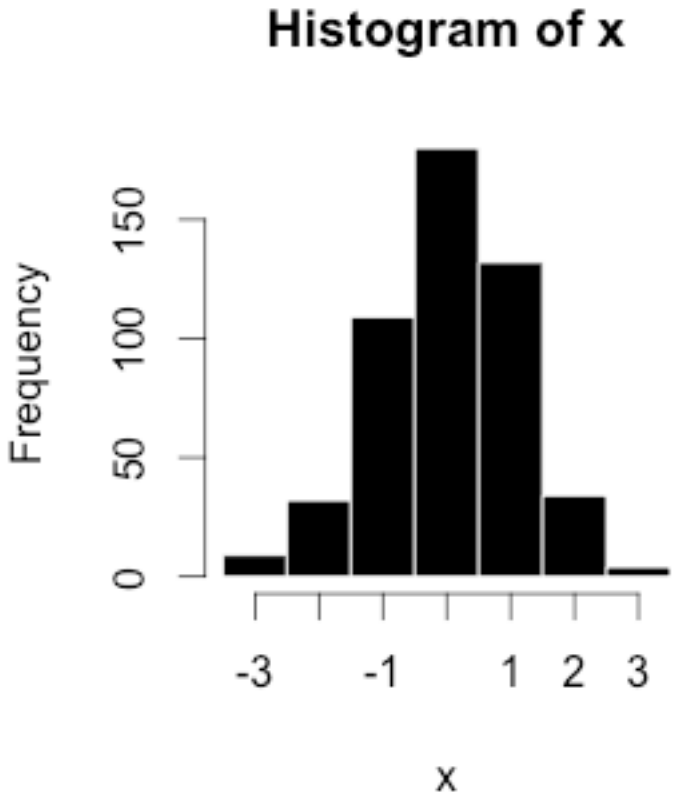
Complete list: http://root.cern.ch/root/html/ClassIndex.html

Histograms

- A histogram is just occurrence counting, i.e. how often a certain outcome appears

-3 -
3.3
2
2.5
-1
1.4
3.4
-2.9
3.3
3.2
3.4
-2.9
2
2.5
-1
....

Bin	Count
[-3.5, -2.5]	9
[-2.5, -1.5]	32
[-1.5, -0.5]	109
[-0.5, 0.5]	180
[0.5, 1.5]	132
[1.5, 2.5]	34
[2.5, 3.5]	4



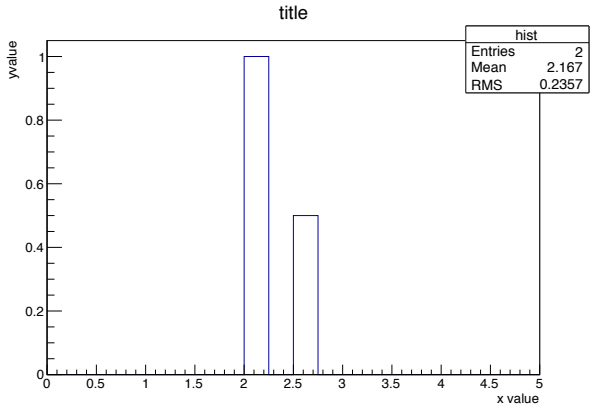
A density estimator

Histograms in ROOT

- Histograms can be:
  - Standard classes: 1D (`TH1`), 2D (`TH2`), 3D(`TH3`)
  - Content: integers (`TH1I`), floats (`TH1F`), double (`TH1D`)

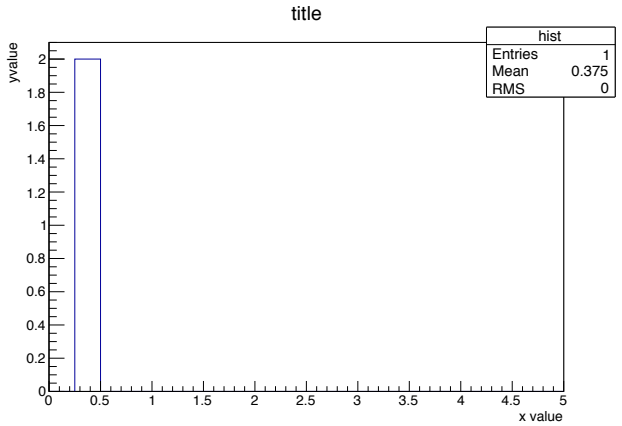
```
>>> from ROOT import TH1F
>>> hist = TH1F("hist", "title; x value; y value", 20, 0, 5)
```

```
>>> hist.Fill(2)
>>> hist.Fill(2.5,0.5)
```



Increase bin at x value by 1 (default) (or 0.5 "weight")

```
>>> hist.SetBinContent(2,2)
```



Set content of bin 2, which corresponds to values $0.25 < x < 0.5$, to 2

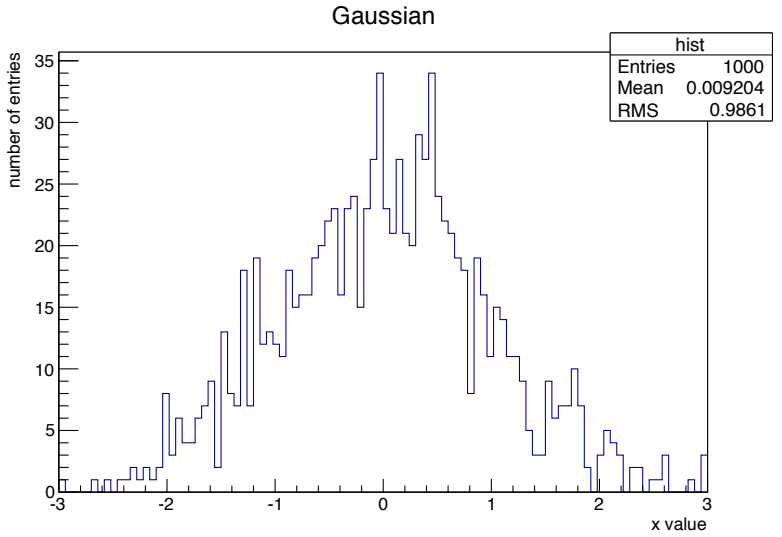
Histograms in ROOT

- Fill histogram according to Gaussian distribution with 1000 entries and extract mean and RMS

```
>>> from ROOT import TH1F
>>> hist = TH1F("hist", "Gaussian", 100, -3, 3)
>>> hist.FillRandom("gaus", 1000)
>>> hist.Draw()
```

```
>>> hist.GetBinContent(58)
34.0
>>> hist.GetMean()
0.009204489559116142
>>> hist.GetRMS()
0.986066762844140
```

```
>>> #Change binning of histogram
>>> hist.Rebin(2)
>>> #Multiply each bin by factor
>>> hist.Scale(2)
```



One can always combine bins (rebin) but not the other way around

Histograms styles


```
>>> hist.Draw("OPTION")
```

https://root.cern.ch/root/html/THistPainter.html

Option	Explanation
"E"	Draw error bars.
"HIST"	When an histogram has errors it is visualized by default with error bars. To visualize it without errors use the option "HIST".
"SAME"	Superimpose on previous picture in the same pad.
"TEXT"	Draw bin contents as text.
Options just for TH1	
"C"	Draw a smooth Curve through the histogram bins.
"E0"	Draw error bars. Markers are drawn for bins with 0 contents.
"E1"	Draw error bars with perpendicular lines at the edges.
"E2"	Draw error bars with rectangles.
"E3"	Draw a fill area through the end points of the vertical error bars.
"E4"	Draw a smoothed filled area through the end points of the error bars.
Options just for TH2	
"COL"	A box is drawn for each cell with a color scale varying with contents.
"COLZ"	Same as "COL". In addition the color palette is also drawn.
"CONT"	Draw a contour plot (same as CONT0).
"SURF"	Draw a surface plot with hidden line removal.

Exercise: Histograms

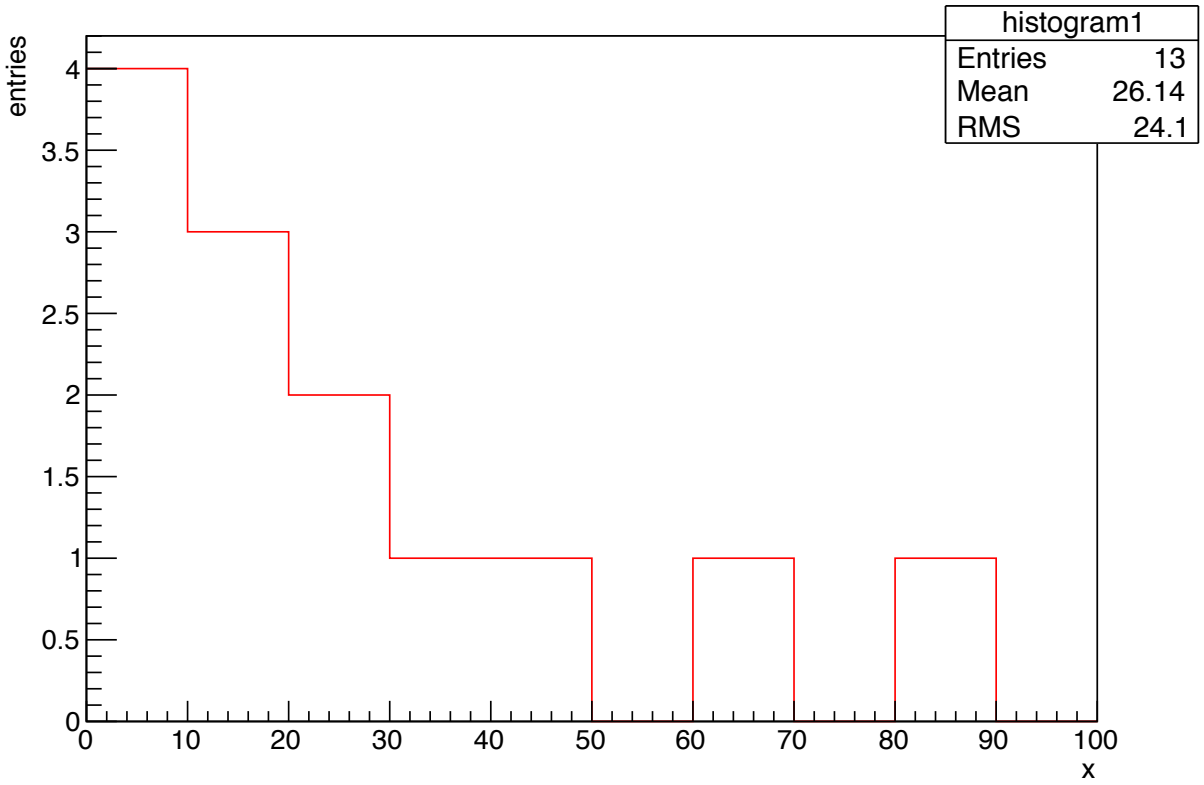
Write a python macro ExerciseHist.py

1. Create a histogram with 10 bins ranging from 0. to 100. with title/x-axis label "x"
2. Fill the histogram at the following numbers: 11.3, 25.4, 18.1
3. Fill the histogram with the square of all integers from 0. to 9.
   (Hint: A simple loop will save you from typing several lines of code)
4. Draw the histogram.
5. Calculate the mean value and the rms and show it on the screen.

   ```
   print mean, rms
   ```
6. Calculate the integral of the histogram.
7. Identify the bin with the maximum number of entries.
8. Find the maximum bin content.
9. Set the y-axis label to "entries".
10. Set the line color of the histogram to red.
11. Run with
    ```
    python -i ExerciseHist.py
    ```

- One dimensional histogram TH1F.
- Constructor of a histogram: TH1F::TH1F(const char* name, const char* title, Int_t nbinsx, Double_t xlow, Double_t xup).
- Fill a histogram: Int_t TH1F::Fill(Double_t x)
- Draw a histogram: void TH1F::Draw(Option_t* option = "")
- Mean of a histogram: Double_t TH1F::GetMean(Int_t axis = 1) const
- RMS of a histogram: Double_t TH1F::GetRMS(Int_t axis = 1) const
- Mode of a histogram: Int_t TH1F::GetMaximumBin() const
- Get the bin content of a histogram: Double_t TH1F::GetBinContent(Int_t bin) const
- Integral of a histogram: Double_t TH1F::Integral(Option_t* option = "") const
- Y-axis used to draw the histogram: TAxis* TH1F::GetYaxis() const
- Access axis and set label void TAxis::SetTitle(char*)
- Change line color of the histogram: void TAttLine::SetLineColor(Color_t lcolor).
  The color index for red is named kRed.

Exercise: Histograms



https://root.cern.ch/root/htmldoc/guides/users-guide/Histograms.htm

Canvas and Legends in ROOT

- ROOT distinguishes between a histogram and a "canvas" where is histogram is drawn on
- Multiple histograms (and other objects) can be drawn on the same canvas with Draw("same")
- Legends can be added to the canvas

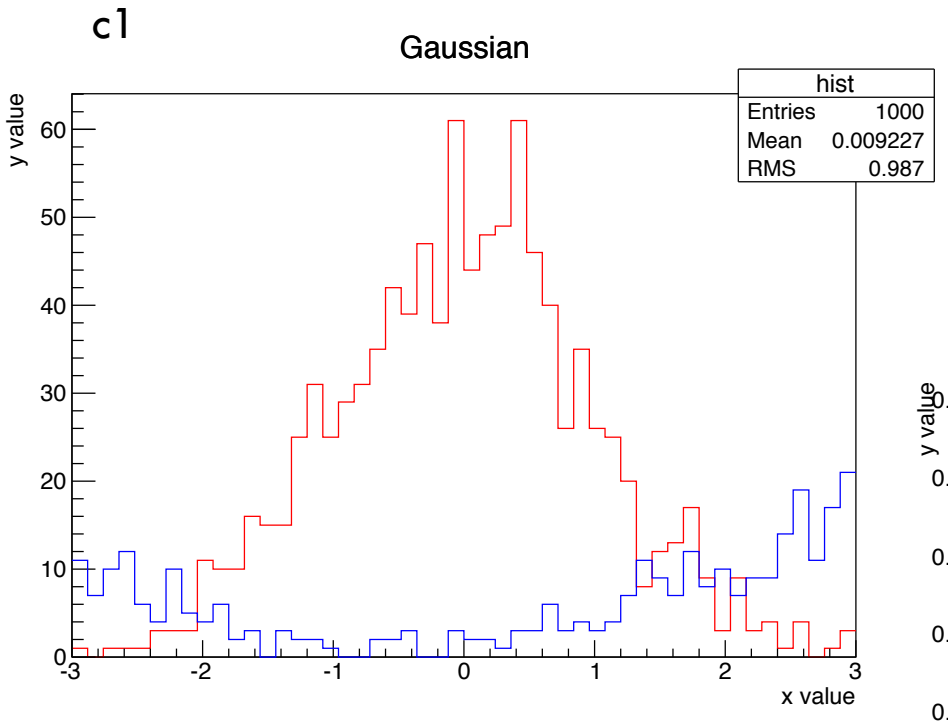
```
>>> from ROOT import Tcanvas,TLegend,TH1F,kRed,kBlue
>>> c = TCanvas("canvas", "canvas", 800 , 600)
...
...
>>> legend = TLegend(0.16, 0.63, 0.45, 0.91)
>>> legend.AddEntry(hist1, "Gaussian", "l")
>>> legend.AddEntry(hist2, "Polynomial", "l")
>>> legend.Draw()
```

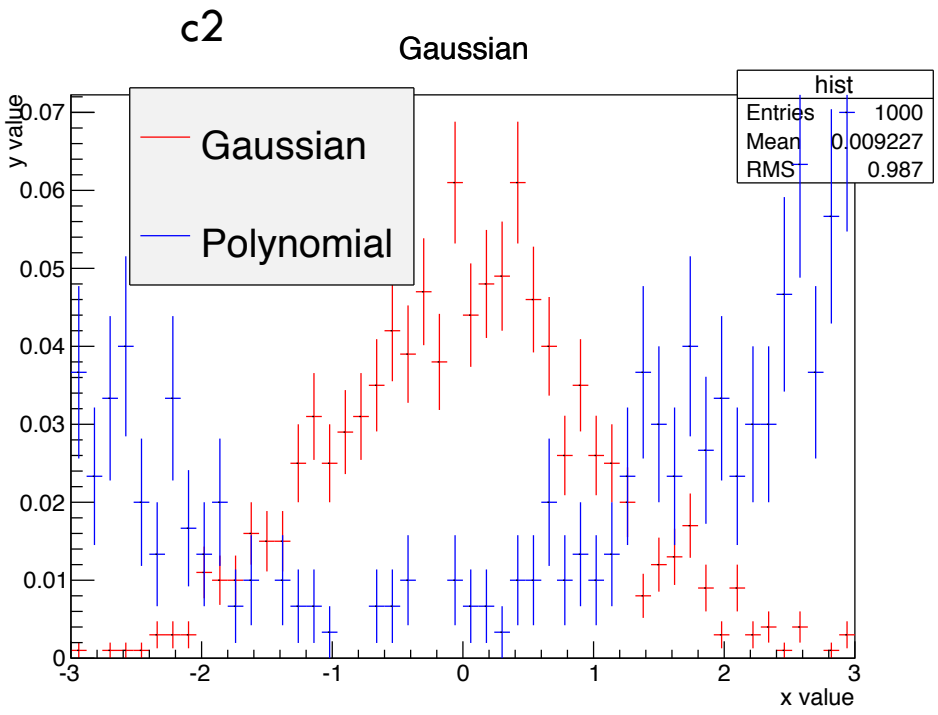
Exercise: Canvas and Legends

Write a python macro ExerciseCanvas.py:

- Create two histograms with 50 bins ranging from -3. to 3. with two different names
- Fill first histogram with Gaussian distribution with 1000 entries
- Fill second histogram with a second order polynomial and 500 entries
  - `hist2.FillRandom("pol2", 500)`
- Create a TCanvas c1 and draw both histograms (option "same" on the second)
- Set the line color of the first histogram to kRed and the second to kBlue. (hist.SetLineColor(kRed))
- Clone both histograms
  - `hist1b = hist1.Clone()`
- Scale both cloned histograms by the inverse of their respective integral, i.e. normalise them to unit area.
- Create a TCanvas c2 and draw both cloned histograms
- Create a legend at position (0.16, 0.63, 0.45, 0.91) and add entries for both histograms to it. Draw the legend.
- Save both canvases as pdf files and as root file
  - `c.SaveAs("filename.pdf")`
  - `c.SaveAs("filename.root")`

Exercise: Canvas and Legends





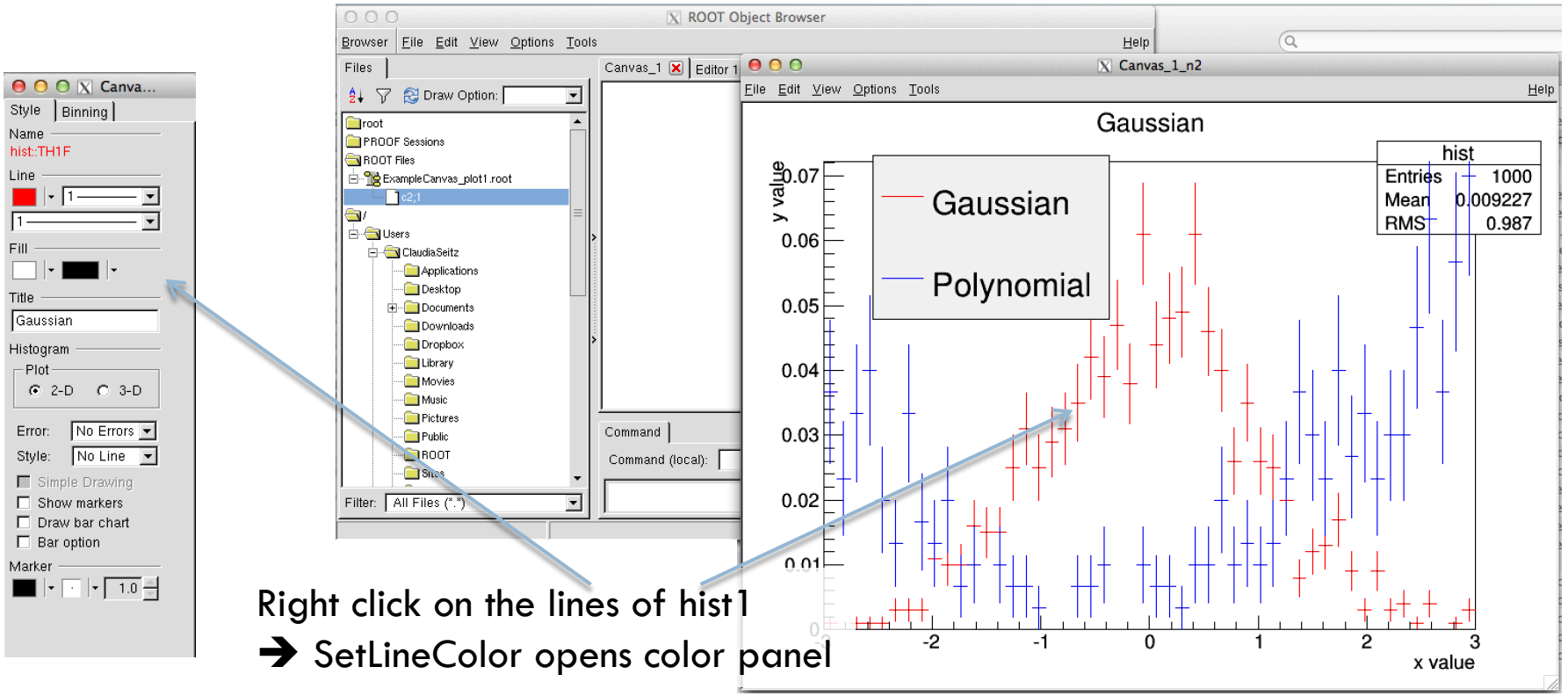
BTW.: errors by default are sqrt(n_{bin})

Graphical User Interface (GUI)

- GUI can be used for visualization and adjustment of styles or plotting on the fly

```
>>> from ROOT import TBrowser,TFile
>>> b = TBrowser()
>>> f = TFile("filename.root")
```

```
root file.root
root [0] new TBrowser
```

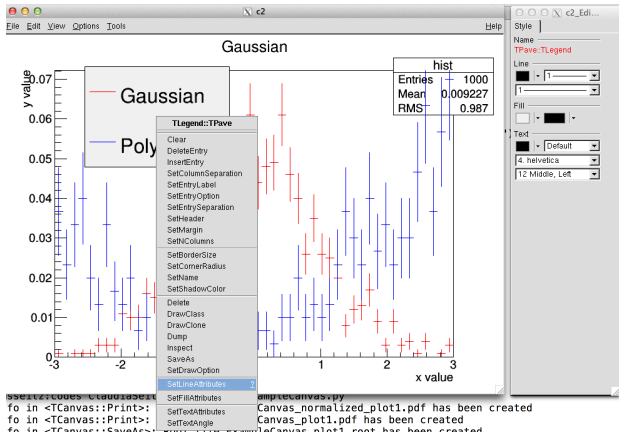


Right click on the lines of hist1

➔ SetLineColor opens color panel

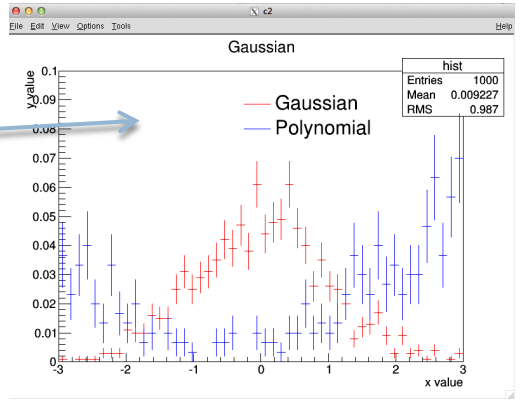
Graphical User Interface (GUI)

- Sometimes changing things by hand are much easier
  - Position of legends (coordinates are given as percentage with respect to the boundaries of the plot)
  - Font sizes of axis labels, offset of lables
- Make the change manually
- Save the canvas as a .C file
- Find the code, import the settings back




```
TLegend *leg = new TLegend(0.4560302,0.7062937,0.7462312,0.8426573,NULL,"brNDC");
leg->SetBorderSize(1);
leg->SetLineColor(0);
leg->SetLineStyle(1);
leg->SetLineWidth(1);
leg->SetFillColor(0);
leg->SetFillStyle(1001);
```

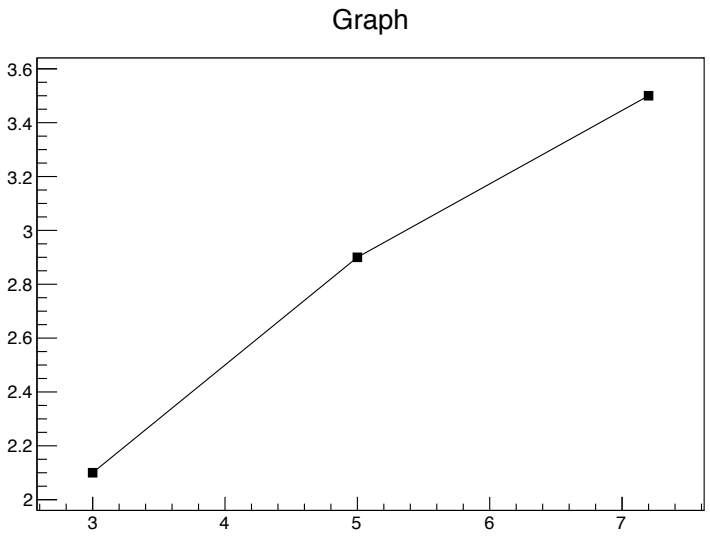
New legend position and settings: white bkg and line color



Graphs in ROOT

- Three main classes for graphs `TGraph`, `TGraphErrors`, `TGraphAsymmetricErrors`
- Graphs are used to display value pairs, errors can be defined to be either symmetric or asymmetric

```
>>> from ROOT import TGraph
>>> #create graph with 3 points
>>> graph = TGraph(3)
>>> #set three points of the graph
>>> graph.SetPoint(0, 3.0, 2.1)
>>> graph.SetPoint(1, 5.0, 2.9)
>>> graph.SetPoint(2, 7.2, 3.5)
>>> #set styles
>>> graph.SetMarkerStyle(21)
>>> graph.SetMarkerSize(1)
>>> #Draw axis (A), points (P), and line (L)
>>> graph.Draw("APL")
```



Functions in ROOT

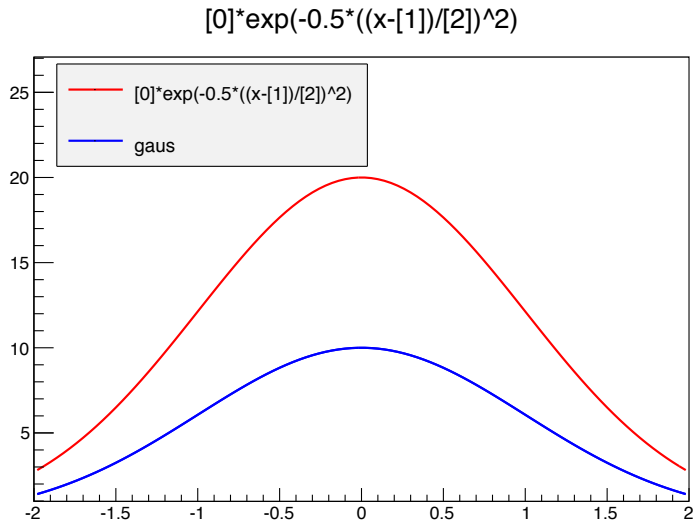
- Classes for TF1, TF2, TF3 for 1 to 3 dimensional functions

```
>>> from ROOT import TF1
>>> #Use of predefined functions “gaus”, “pol1”,”pol3”, etc.
>>> fGaus = TF1("fGaus", "gaus", -2, 2)

>>> #Use of custom user functions
>>> f = TF1("f","[0]*exp(-0.5*((x-[1])/[2])^2)", -2, 2)
```

```
>>> #Setting the parameters
>>> f.SetParameter(0,20)
>>> f.SetParameter(1,0)
>>> f.SetParameter(2,1)

>>> fGaus.SetParameter(0,10)
>>> fGaus.SetParameter(1,0)
>>> fGaus.SetParameter(2,1)
```

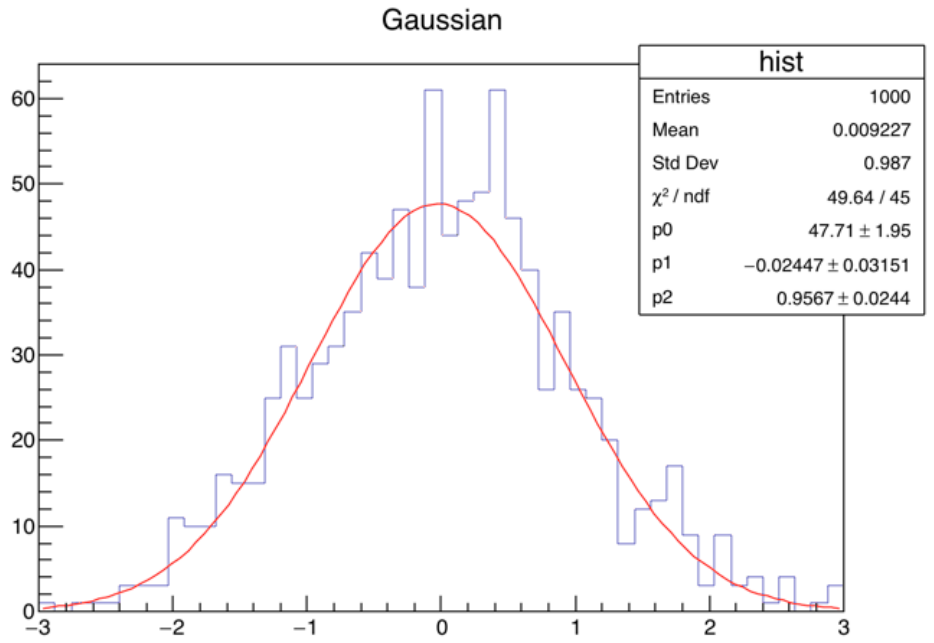


Fitting in ROOT


```
>>> hist.Fit("fGaus”)
 FCN=97.4876 FROM MIGRAD    STATUS=CONVERGED      67 CALLS          68 TOTAL
                     EDM=3.44445e-08    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                          STEP         FIRST
  NO.   NAME      VALUE            ERROR                 SIZE      DERIVATIVE
   1  Constant     2.29946e+01   1.02159e+00   3.70880e-03   2.59473e-04
   2  Mean        -2.11506e-03   3.28869e-02   1.58874e-04   5.12360e-03
   3  Sigma        9.50152e-01   3.00472e-02   3.74233e-05   1.80927e-02
<ROOT.TFitResultPtr object at 0x7fa0db5b9e70>
```

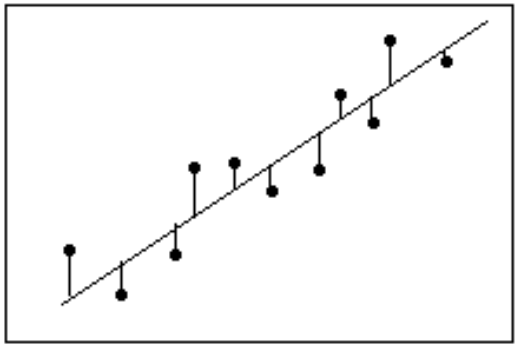
```
>>> hist.Draw()
>>> fGaus.Draw("same")
```

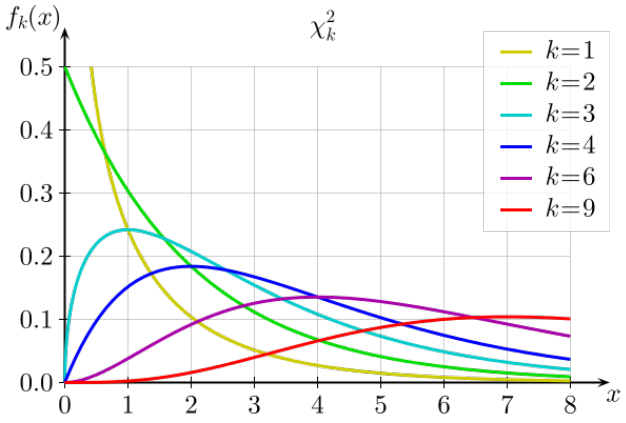
Option->Show Fit Parameters



More on Fits and Fitting Quality

- Most common fit method: (Weighted) Least Squares
  - $\min_{\theta} \sum_i \{y_i - f(x_i, \theta)\}^2$ (weighted: divide by error)
  - $\chi^2 \sim \sum \{y_i - f(x_i, \theta)\}^2$ distribution of residuals Depends on
  - χ^2 probability distribution depends on DOF
    - E.g. 20 measurements Gaussian fit (N,μ, σ) -> DOF=20-3





- https://root.cern.ch/root/htmldoc/guides/users-guide/FittingHistograms.html

Exercise: Graphs and Fits

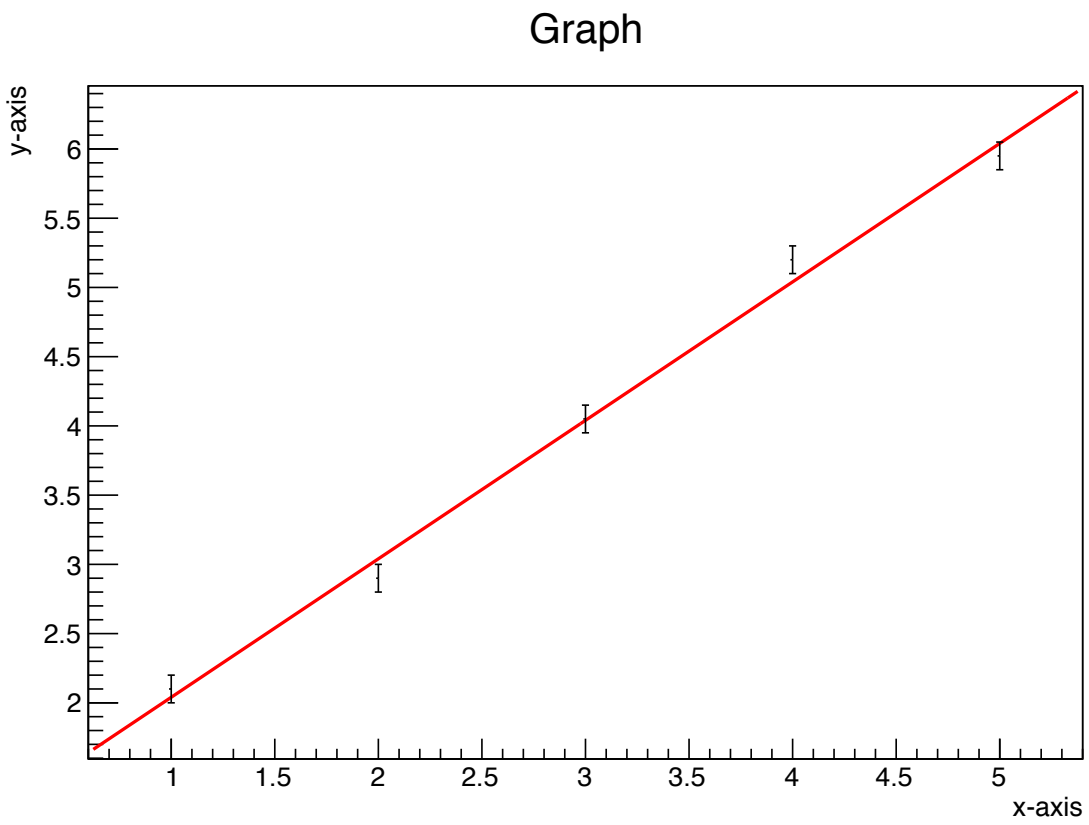
Write a python macro ExerciseGraph.py:

- Create a graph with symmetric errors and 5 points.
- Set the following points (0-4): (1.0, 2.1), (2.0, 2.9), (3.0, 4.05), (4.0, 5.2), (5.0, 5.95)
- Set the errors on x to 0.0 and the errors on y to 0.1.
- Draw the graph including the axes and error bars.
- Create a one dimensional function f(x)=mx + b and fit it to the graph.
- Obtain the two parameters a and b from the function and their estimated uncertainties.

Take the Gaussian histogram from the previous exercise (ExerciseCanvas.py) and fit a Gaussian. Is it a good fit?

- A one dimensional graph TGraphErrors.
- A constructor of a graph: TGraphErrors::TGraphErrors(Int_t n).
- A method to set the points of a graph: void TGraphErrors::SetPoint(Int_t i, Double_t x, Double_t y).
- A method to set the errors of a graph: void TGraphErrors::SetPointError(int i,Double_t ex, Double_t ey).
- A method to fit a graph with a function: TFitResultPtr TGraphErrors::Fit(const char *fname, Option_t *option, Option_t *, Axis_t xmin, Axis_t xmax).
- A method to return the parameters of a function: Double_t TF1::GetParameter(Int_t ipar).
- A method to return the errors on the parameters of a function: Double_t TF1:GetParError(Int_t ipar) const .

Exercise: Graphs and Fits



Classes: TFile and TTree

- TFile is basic I/O format in root
  - Open an existing file (read only)
    - `InFile = TFile("myfile.root", "OPTION")`
      - `OPTION = leave blank (read only), "RECREATE" (replace file), "UPDATE" (append to file)`
    - Files can contain directories, histograms and trees (ntuples) etc.
- ROOT stores data in TTree format
  - Tree has "entries" (e.g. collision events) each with identical data structure
  - Can contain floats, integers, or more complex objects (whole classes, vectors, etc…)
  - TNtuple is a tree that contains only simple variables

Creating a TTree from text file

- Copy the following text file
  - `cp /afs/desy.de/user/k/kruecker/public/sst2019_root/basic.dat .`
  - Or from this link

```
>>> from ROOT import TFile,TTree
>>> f = TFile("ntuple.root","RECREATE")
>>> t = TTree("ntuple","reading data from ascii file")
>>> t.ReadFile("basic.dat","x:y:z")
>>> t.Write()
```

```
[nafhh-cms02] ~ more basic.dat
-1.102279 -1.799389 4.452822
1.867178 -0.596622 3.842313
-0.524181 1.868521 3.766139
-0.380611 0.969128 1.084074
0.552454 -0.212309 0.350281
-0.184954 1.187305 1.443902
0.205643 -0.770148 0.635417
```

Working with TTrees

- Get the following root file (or use from previous page)
  - `cp /afs/desy.de/user/k/kruecker/public/sst2019_root/basic.root .`

```
>>> from ROOT import TFile
>>> f = TFile("basic.root")
>>> t = f.Get("ntuple")
```

```
>>> t.Show(2)
======> EVENT:2
 x               = -0.524181
 y               = 1.86852
 z               = 3.76614
```

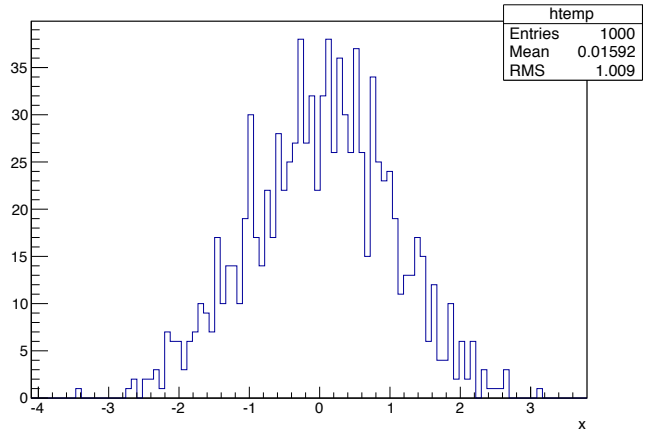
Shows the content and structure of the tree for one entry

```
>>> t.Scan()
************************************************
*    Row   *         x *         y *         z *
************************************************
*        0 * -1.102278 * -1.799389 * 4.4528222 *
*        1 * 1.8671779 * -0.596621 * 3.8423130 *
*        2 * -0.524181 * 1.8685209 * 3.7661390 *
*        3 * -0.380611 * 0.9691280 * 1.0840740 *
```

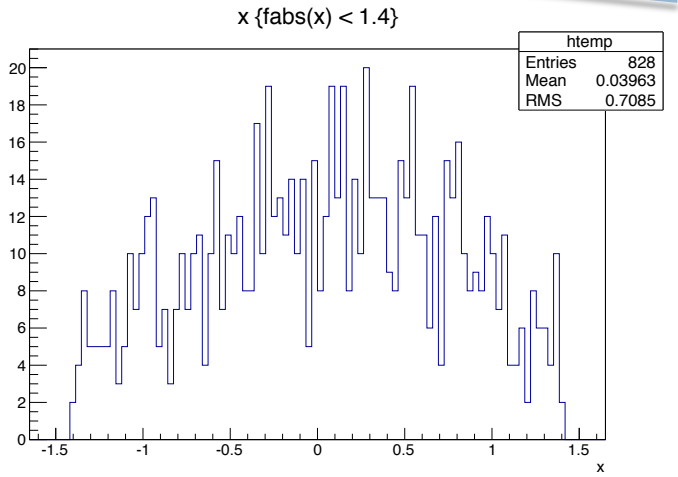
Shows one or multiple variables for all entries

Plotting quantities directly from TTrees


```
>>> t.Draw("x")
```



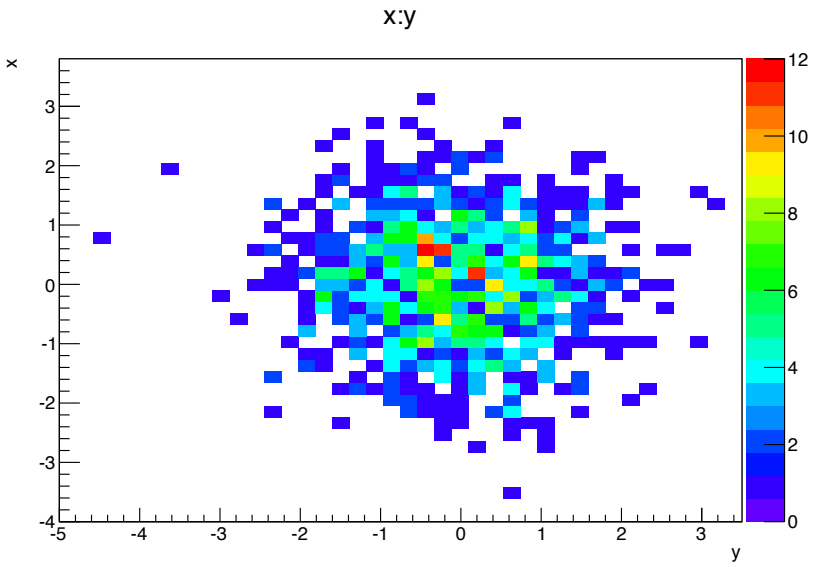

```
>>> t.Draw("x","fabs(y) < 1.4","")
829L
```



number tells you how many entries passed condition

Scatter plot shows the correlation between variables

```
>>> T.Draw("x:y","","colz")
```



TTree functions (very useful for quick checks)

Command	Action
`t.Print()`	Prints the content of the tree
`t.Scan()`	Scans the rows and columns
`t.Draw("x")`	Draw a branch of tree

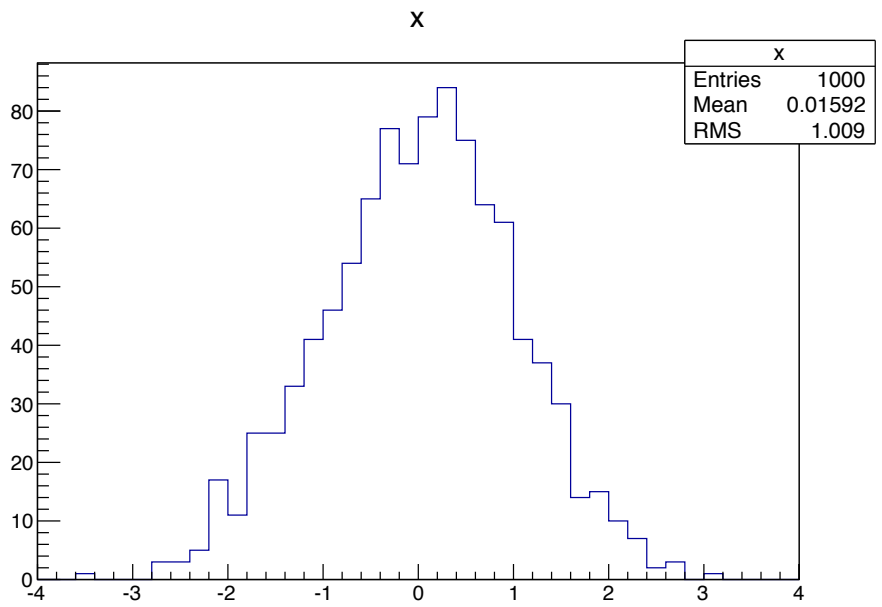
How to apply cuts:
`t.Draw("x", "x>0")`
`t.Draw("x", "x>0 && y>0")`
	
	Draw “x” when “x>0”
	Draw “x” when both x >0 and y >0

`t.Draw("y", "", "same")`	Superimpose “y” on “x”
`t.Draw("y:x")`	Make “y vs x” 2d scatter plot
`t.Draw("z:y:x")`	Make “z:y:x” 3d plot
`t.Draw("sqrt(x*x+y*y)")`	Plot calculated quantity
`t.Draw("x>>h1")`	Dump a root branch to a histogram

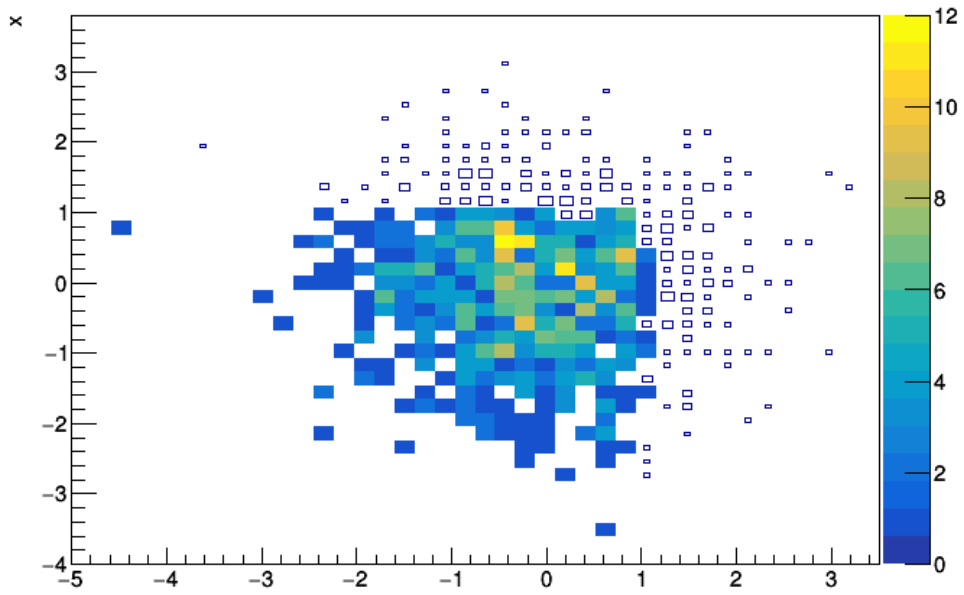
Looping through entries of a TTree


```
>>> from ROOT import TFile,TH1D
>>> f = TFile("basic.root")
>>> t = f.Get("ntuple")
>>> nEntries = t.GetEntries()
>>> hist = TH1D("x", "x",40,-4,4)
>>> for i in range(0,nEntries):
...     entry = t.GetEntry(i)
...     hist.Fill(t.x)
...
>>> hist.Draw()
```

```
....
>>> for evt in t:
...     hist.Fill(evt.x)
...
```



Draw with Cuts

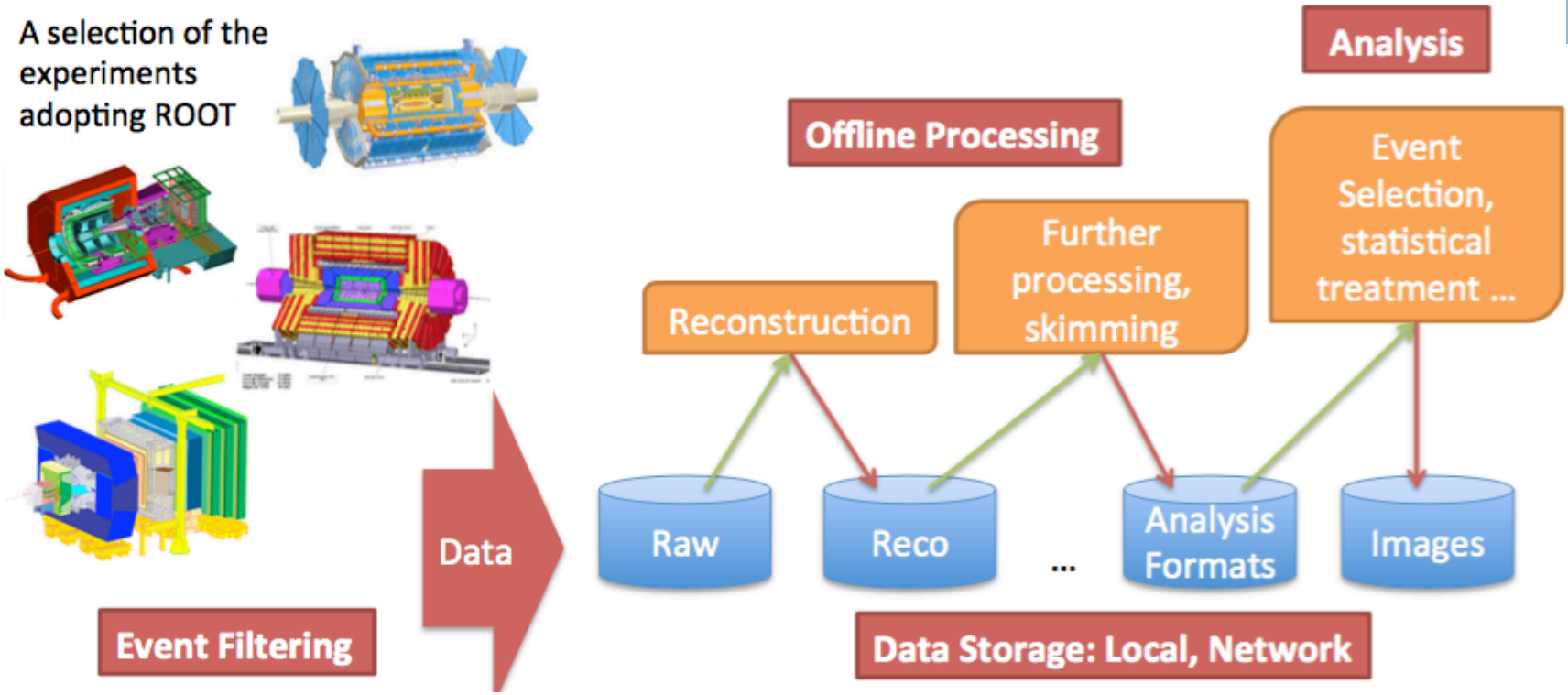



```
root /afs/desy.de/user/k/kruecker/public/sst2019_root/basic.root
>>> ntuple->Draw("x:y","","box")
>>> ntuple->Draw("x:y","x<1&&y<1","colzsame")
```

Exercise: Tree

- Do p41-p46

Ntuples, Trees and Flat Ntuples

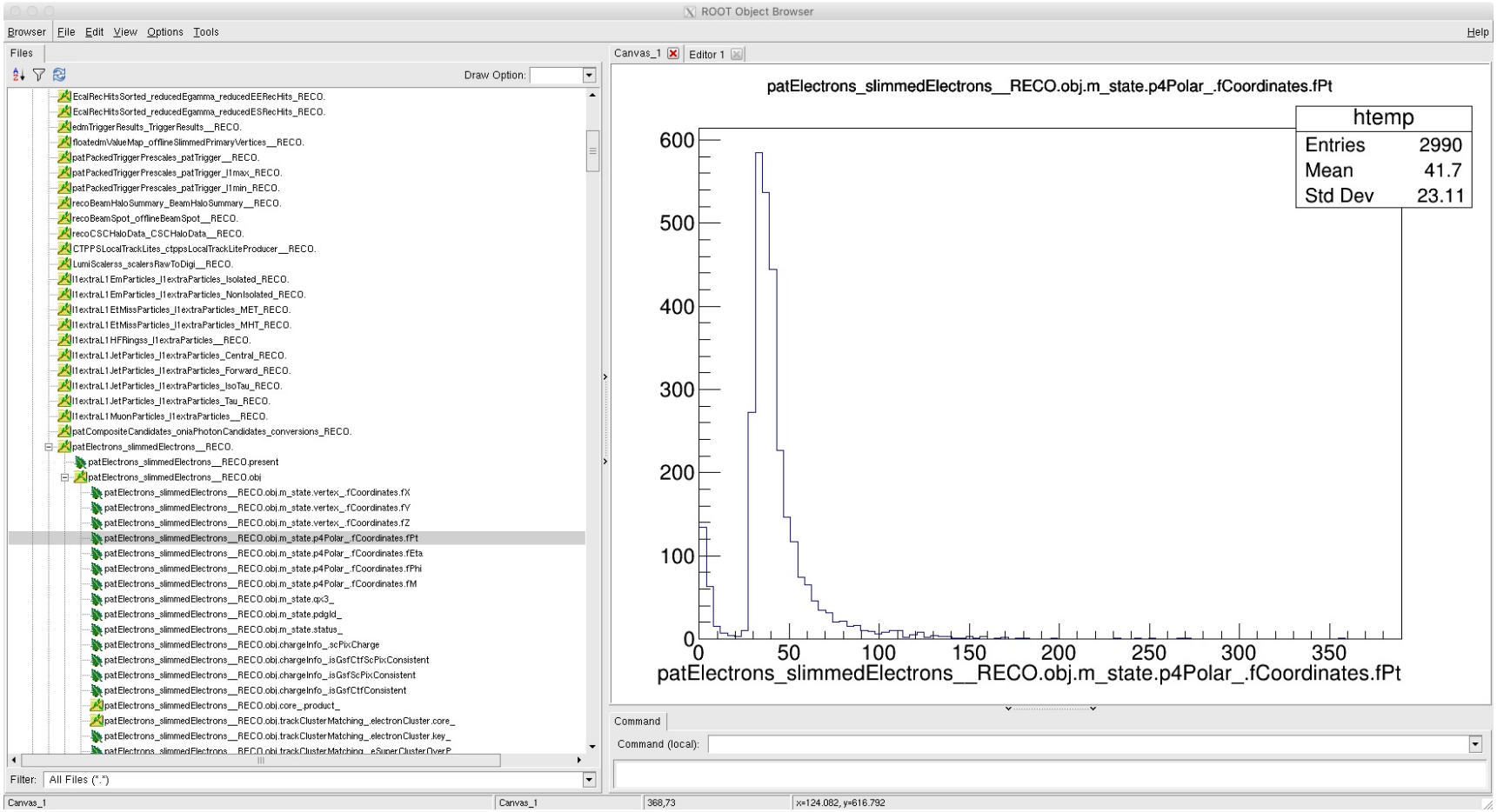


- RAW->RECO->AOD->miniAOD->nanoAOD
  ->custom made
  (Or not so flat) "**flat ntuple**"

Custom made ntuples

- For example CMS data, same for all other experiments, is extremely complex
- Large files, distributed over several places in the world, dozens of TB
- A skimming to get smaller files is always a good idea
- For easy access you either want to have a flat list of variables, or
- Sometimes it is more convenient to define your own object, classes i.e. a Electron, Jet etc.
- ROOT can learn this if you provide the class definition with the necessary information, which are different for each analysis/group

CMSSW root file



ROOT must know the class definition. This is done within CMSSW

Here we use a simpler example:

Exercise: Custom Made Trees

Get the class.h and the root file

~kruecker/public/sst2019_root/hoAnaTree.root

Write a 2 python macros Tree1.py Tree2.py:

- Load the classes.h within your python script
- Read in the file hoMuonAnalyzer/tree and fill the first muon globMu[0] energy into a histogram (50 bins 0-500GeV)
- Do it by a python loop as on p43
- Try a second way (tree2.py) and do it by tree.Draw("globMu[0].E()>>hist") command
- Check the times (Do not show the histogram when you take the time)
- Try the timing with the larger file hoAnaTree_ZMu-PromptReco-v3.root
- Measure the time for the tree processing within the scripts with timeit

- To execute commands as if you are at the ROOT command line gInterpreter.ProcessLine('.L classes.h')
- Timing from the command line:

  time python tree1.py
- The class globMu (global muons) are vectors of 4-vectors
- muon_energy = t.globMu[0].E()
- A python module for measure times

```
import timeit
start=timeit.timeit()
....
stop=timeit.timeit()
print sttop-start
```

The End

https://root.cern.ch/courses

Have fun!

Material for this lecture:

/afs/desy.de/user/k/kruecker/public/sst2019_root

or at

https://desycloud.desy.de/index.php/s/RZgiy5fkHjtd5rf

Additional background:

https://en.wikipedia.org/wiki/ROOT

new approaches

You love python?

Check out uproot:

https://indico.cern.ch/event/686641/contributions/2894906/attachments/1606247/2548596/pivarski-uproot.pdf

http://uproot.readthedocs.io/en/latest/root-io.html

Useful Links

- Linux tutorial
  - http://www.ee.surrey.ac.uk/Teaching/Unix/
- C++
  - Tutorial http://www.learncpp.com/
  - Tutorial and reference http://www.cplusplus.com/doc/tutorial/
- Python
  - Interactive tutorial https://www.codecademy.com/en/tracks/python
  - Tutorial
- Git
  - Introduction https://guides.github.com/activities/hello-world/
  - Interactive tutorial http://pcottle.github.io/learnGitBranching/

connecting

Windows

- e.g. http://mobaxterm.mobatek.net/
- mobaXterm->new session->ssh,server bastion.desy.de

Mac

- https://www.xquartz.org/

ssh –Y user@naf-XXX.desy.de (ask your supervisor for the name)

Web

- https://nafhh-x2.desy.de:3443/auth/ssh