

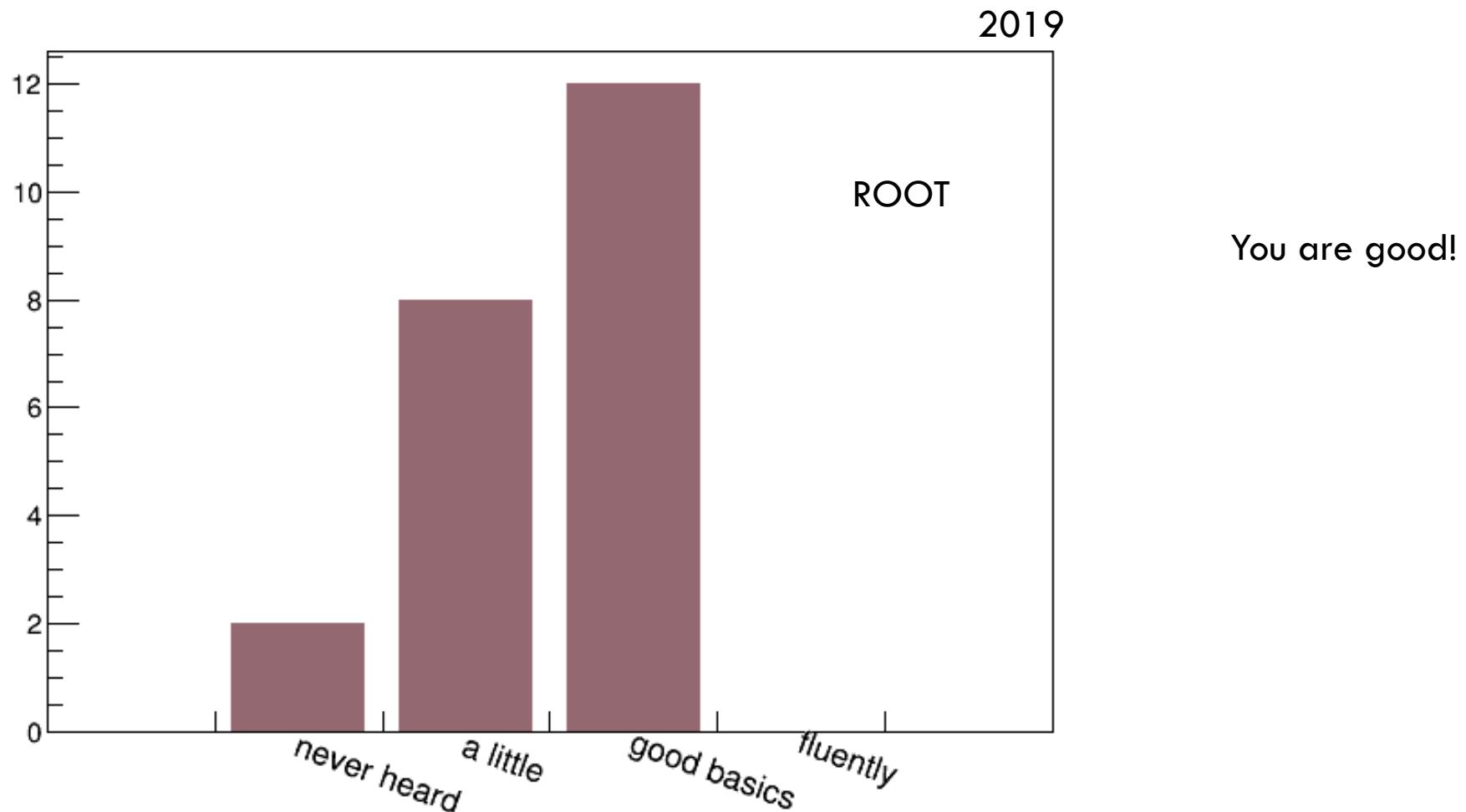
ROOT TUTORIAL

David Brunner, Dirk Krücker, Ashraf Mohamed

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

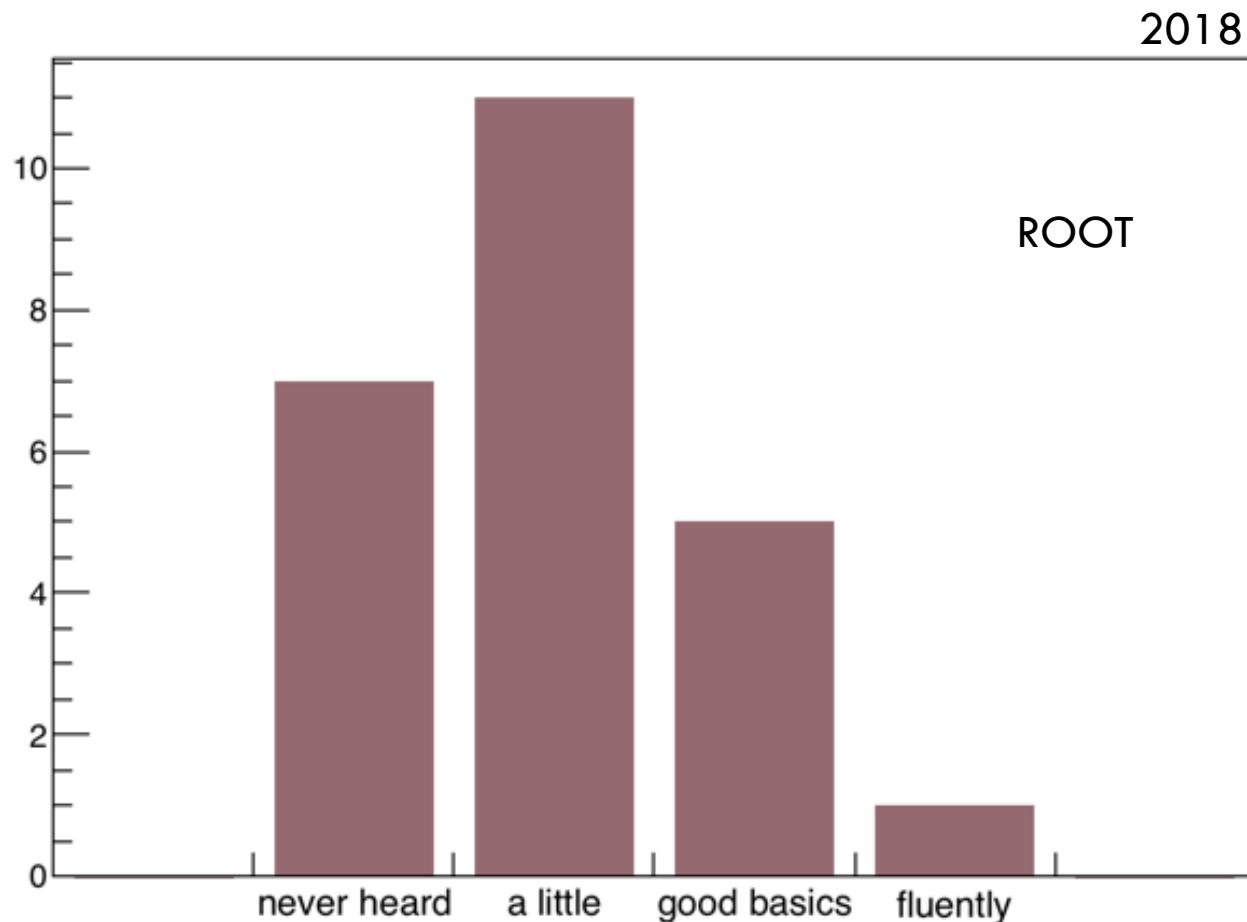
Questionnaire on ROOT Experience

2



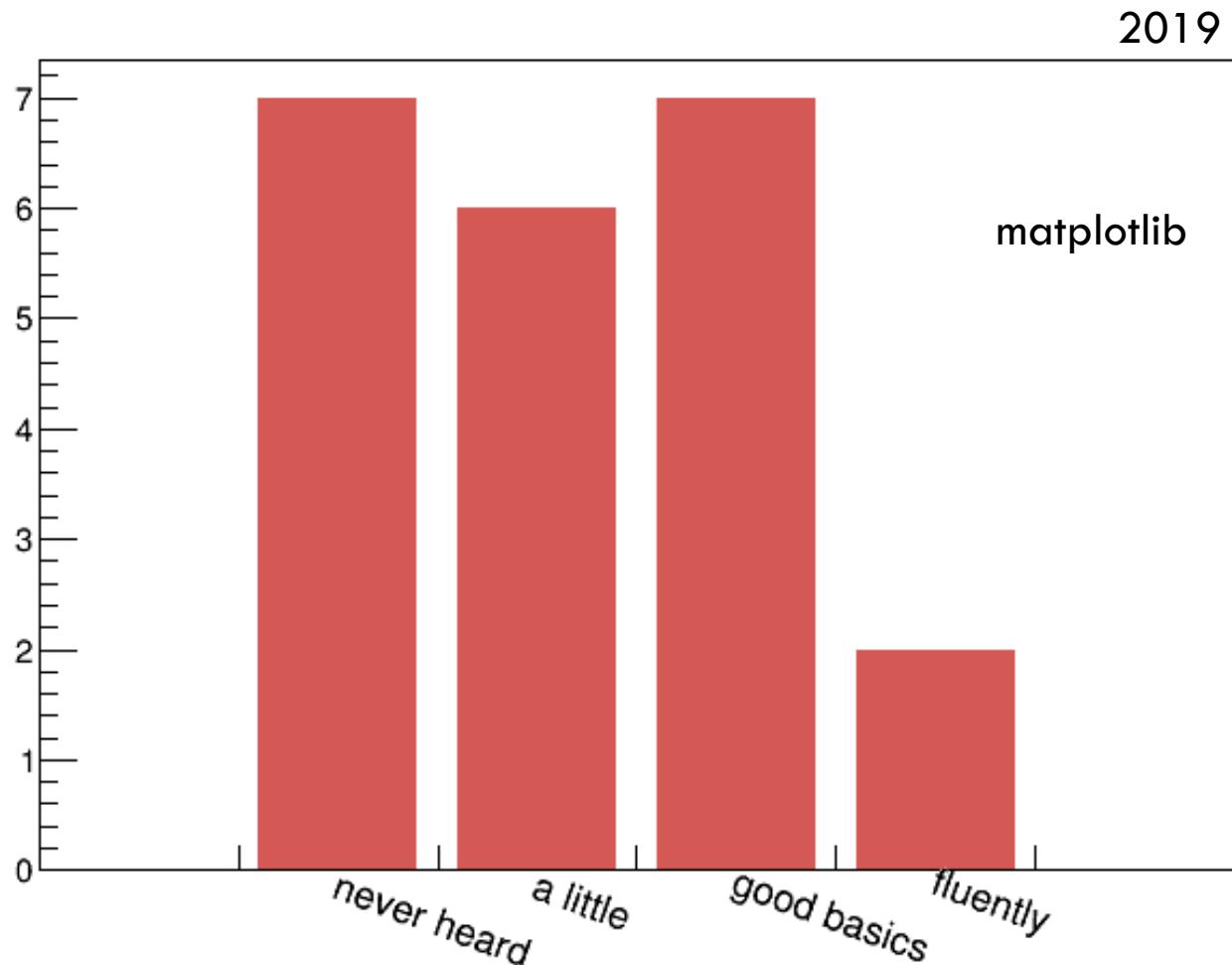
Questionnaire on ROOT Experience

3



Questionnaire on Matplotlib Experience

4

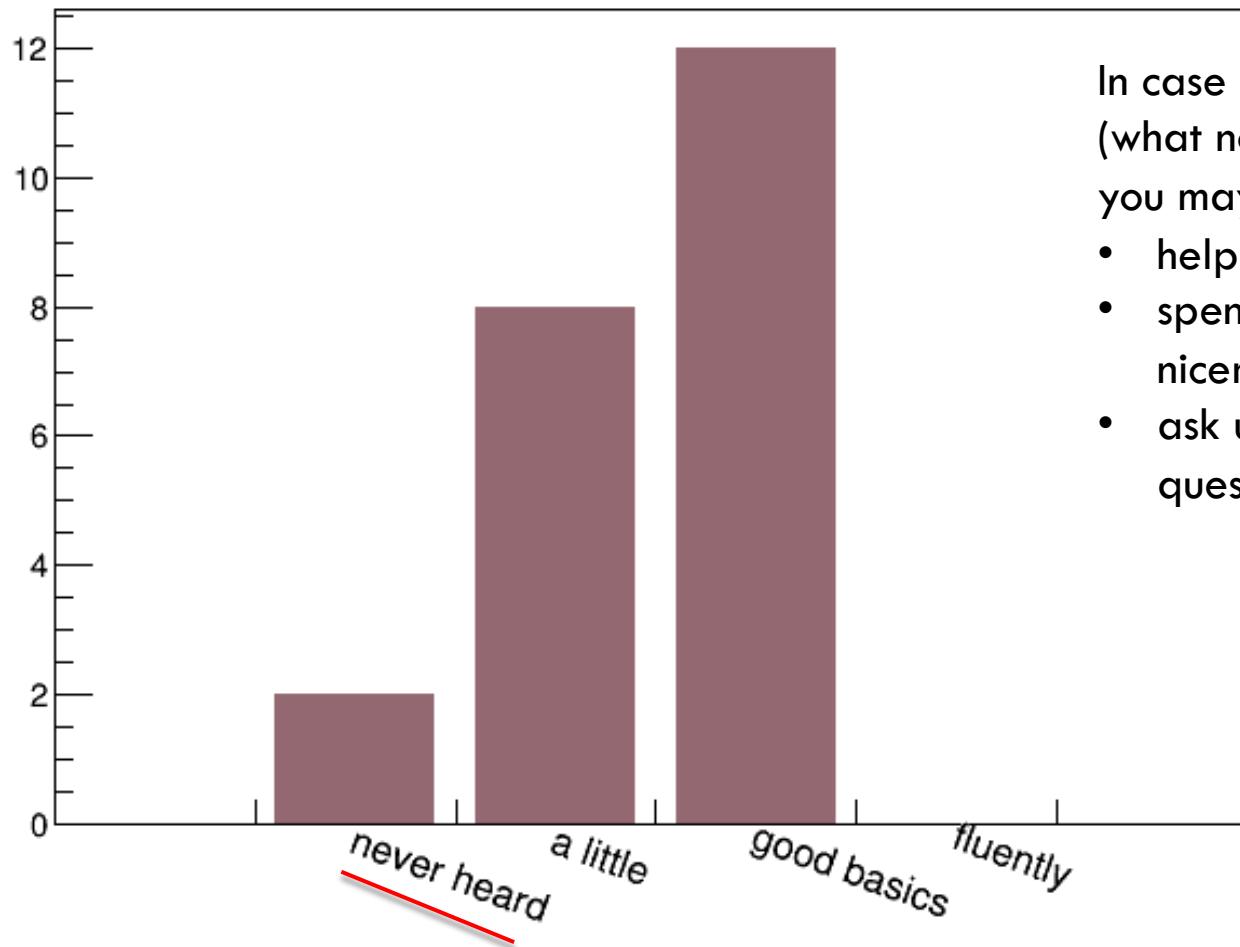


Popular in
data science
e.g. deep learning

Questionnaire on ROOT Experience

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**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?

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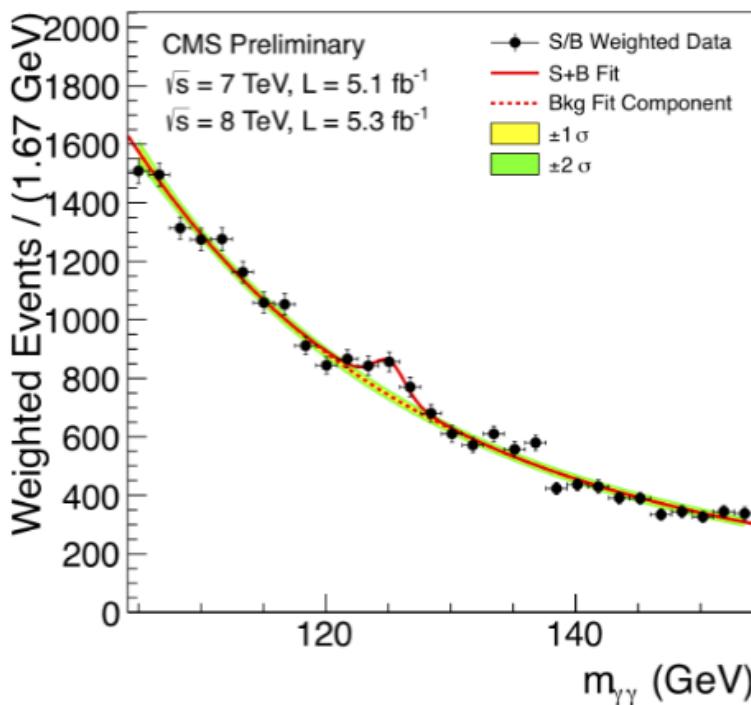
- ROOT is the **Swiss Army Knife of High Energy Physics**
- It will be with you for the rest of your scientific career in HEP



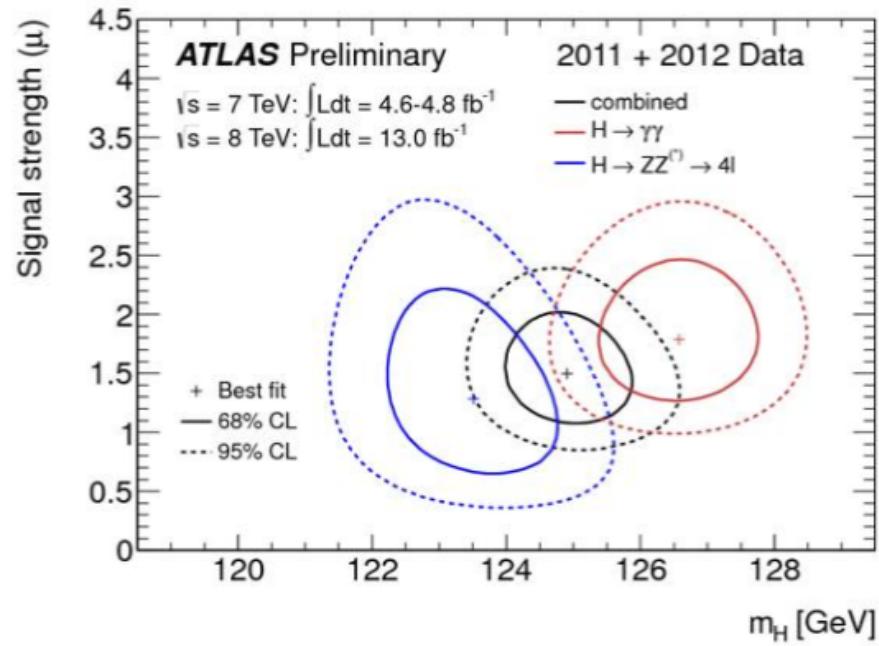
What is ROOT

7

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



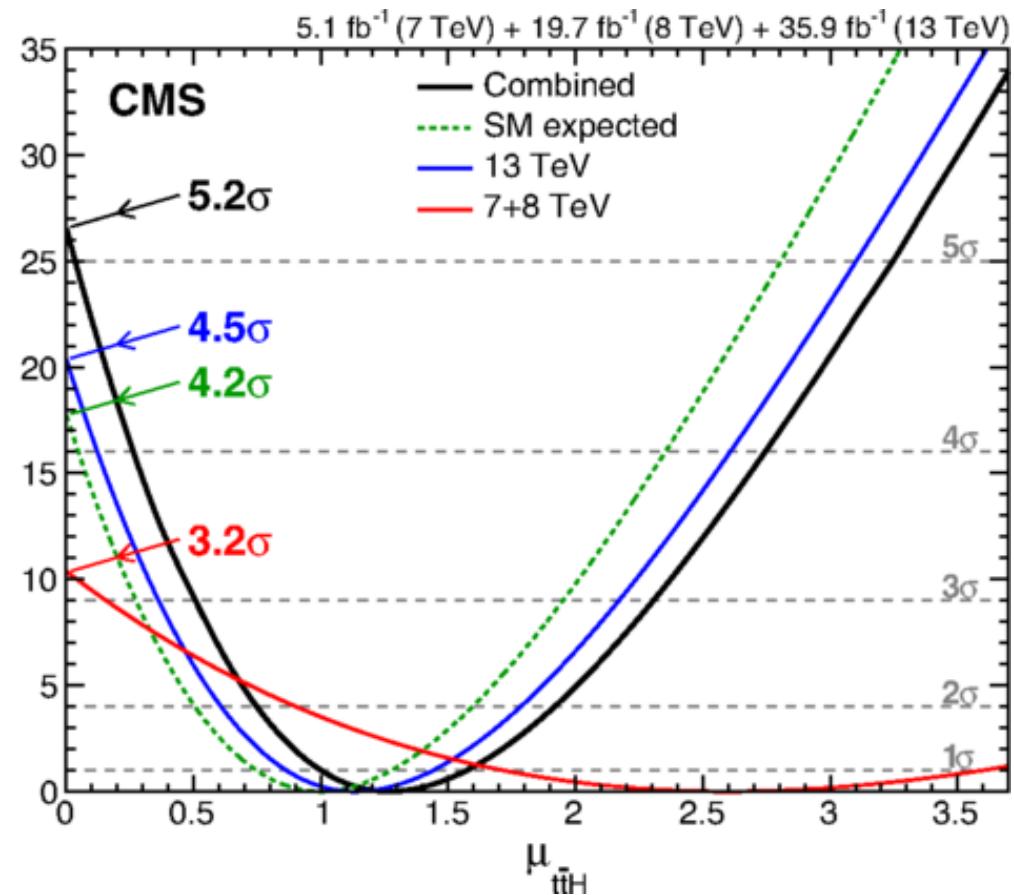
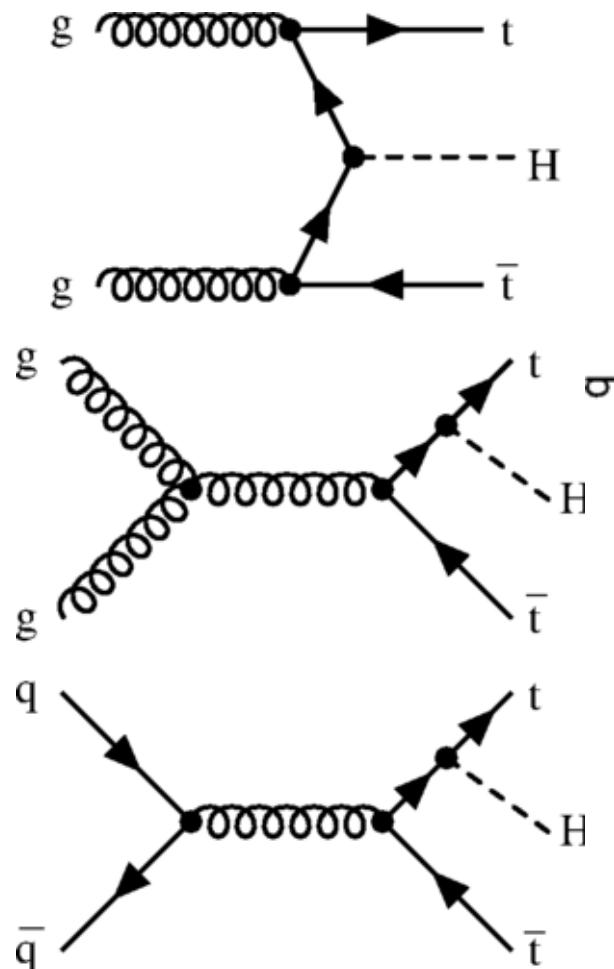
LHC collision in CMS:
event display, also done with ROOT!



Observation of ttH by CMS and ATLAS

2018 - another ROOT Plot

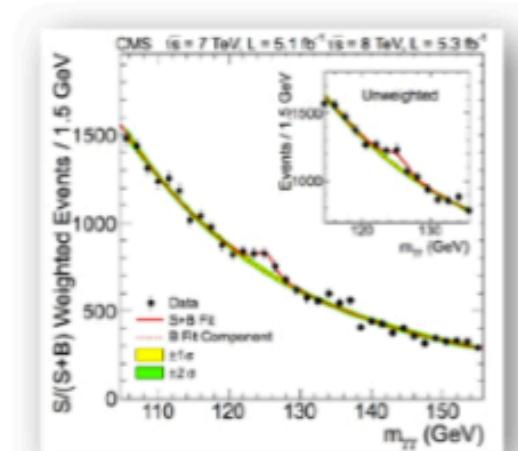
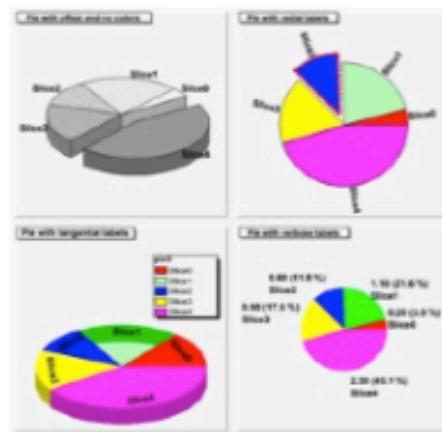
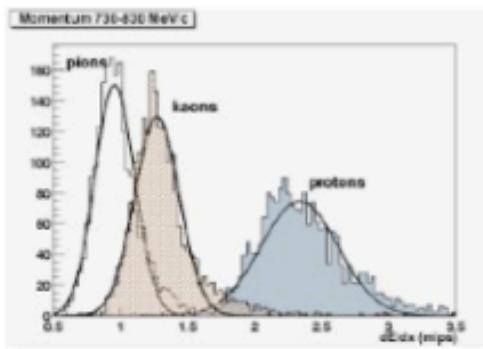
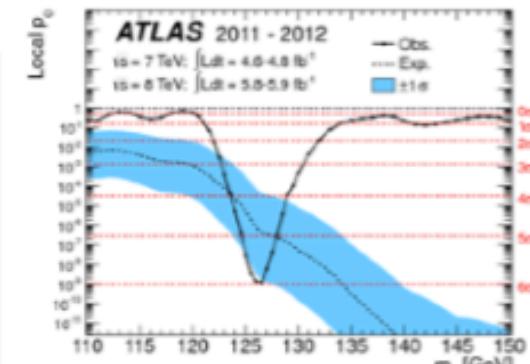
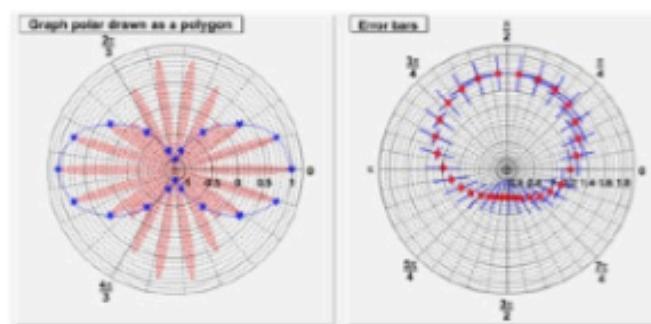
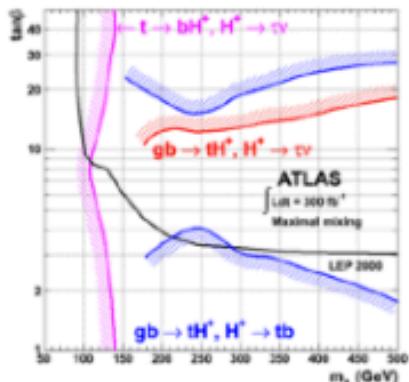
8



What is ROOT

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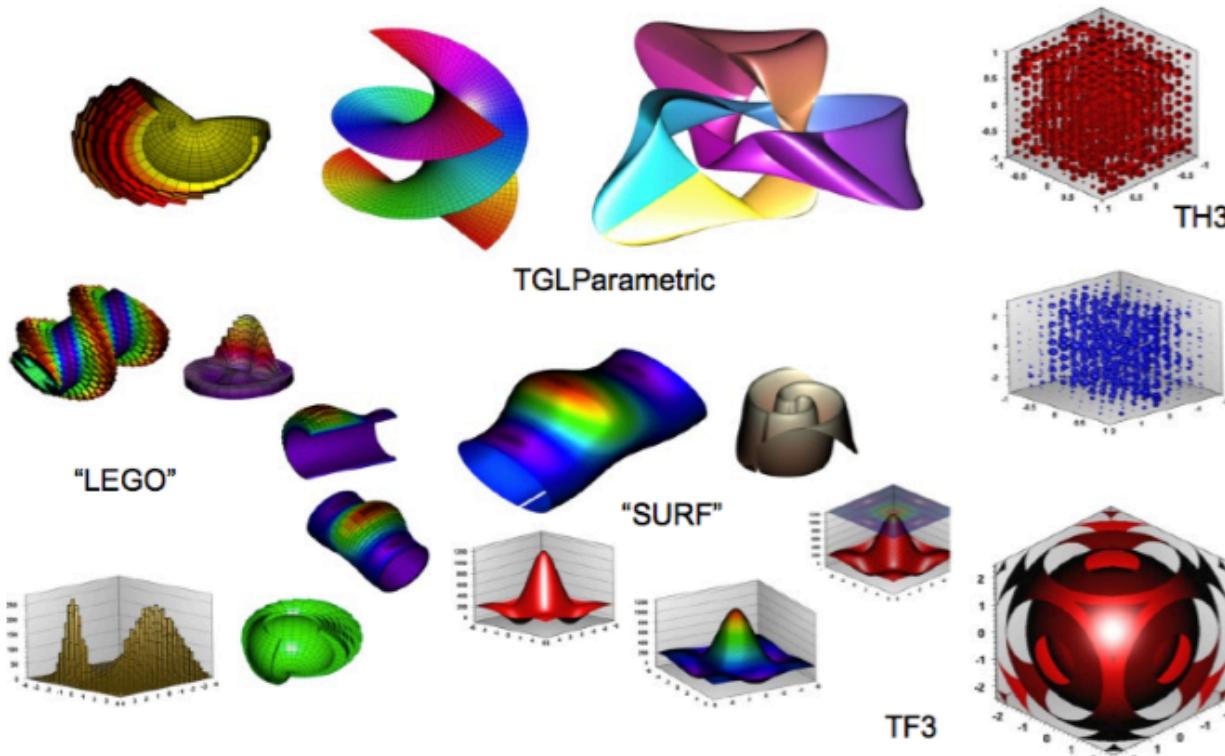
Many formats for data analysis, and not only, plots



What is ROOT

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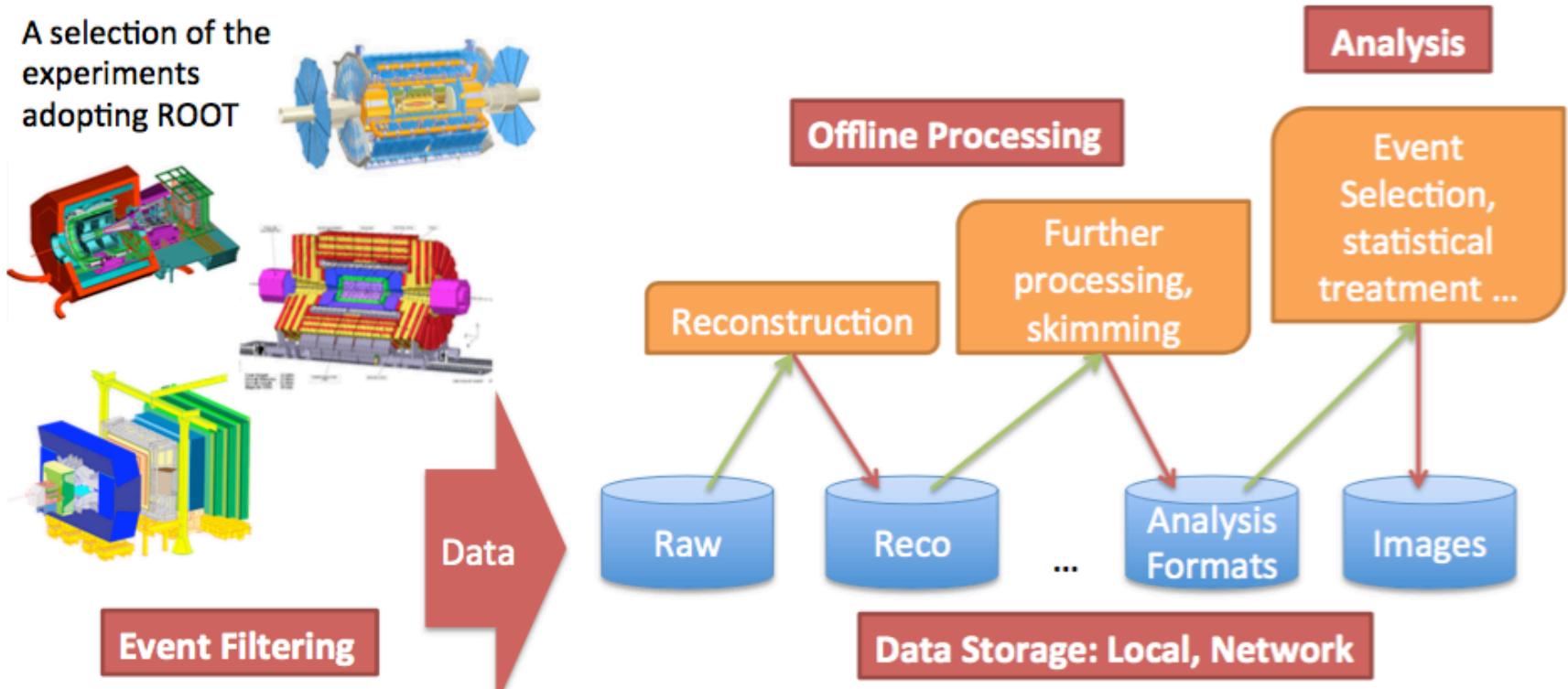
- more plots in 3D



What is ROOT

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- Data format for the LHC (and other) experiments



ROOT

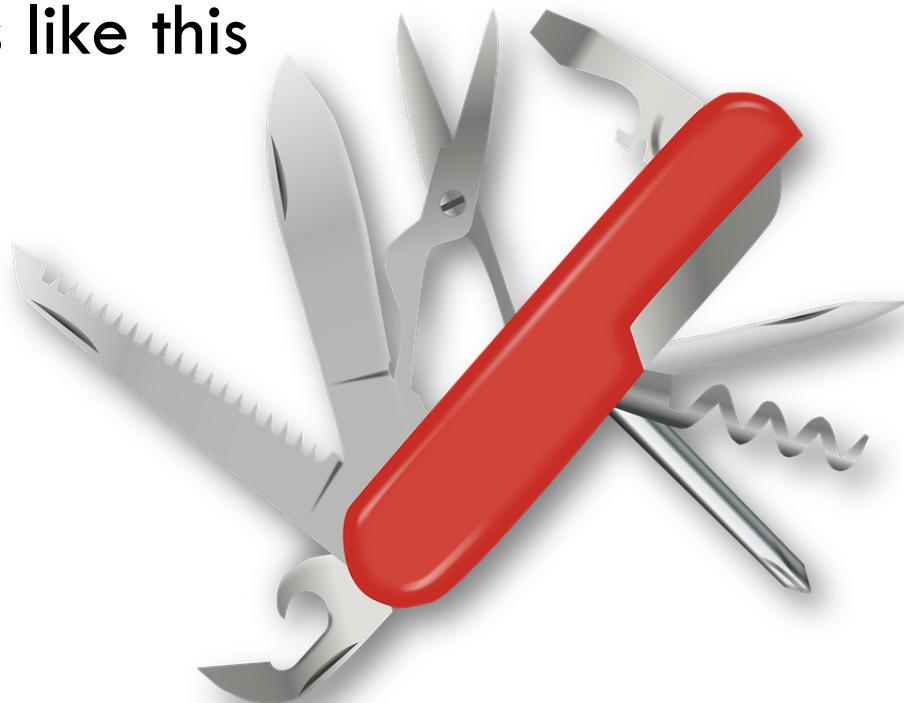
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- ROOT is an analysis software that is used extensively in particle physics
- The three main aspects are:
 - **Graphics/Plotting**
 - Various 1-dim up to n-dim histogram formats
 - Graphs and functions
 - **Data analysis**
 - Math libraries
 - Statistical 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?

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



What is ROOT

14

- 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

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- 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
 - ssh pal.desy.de
source /cvmfs/sft.cern.ch/lcg/views/LCG_93c/x86_64-centos7-gcc62-opt/setup.sh
- 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!*

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□ 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

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- 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

18

- 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

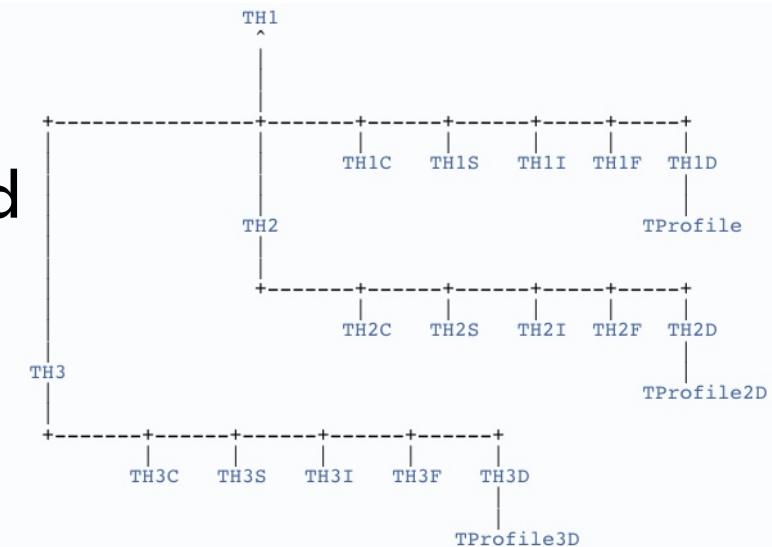
```
double Example(double x){  
    double x2 = x*x;  
    return x2;  
}
```

C++

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

□ Inheritance

solve a problem only once and re-use the code



Crash Course in OO Programming

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

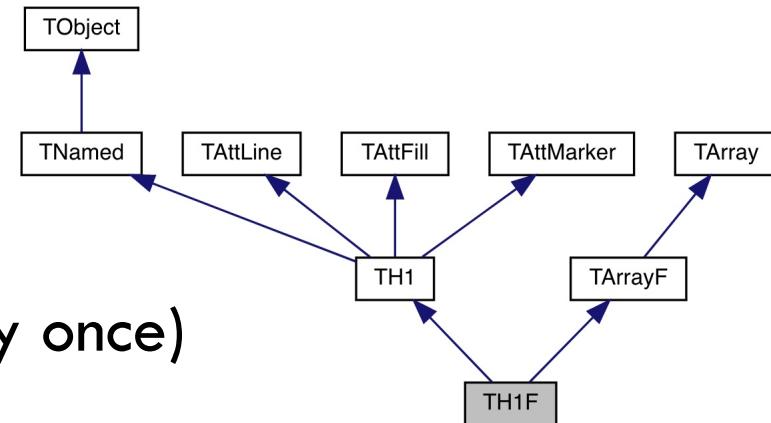
```
def Example(x):  
    x2 = x*x  
    return x2
```

Python

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

C++

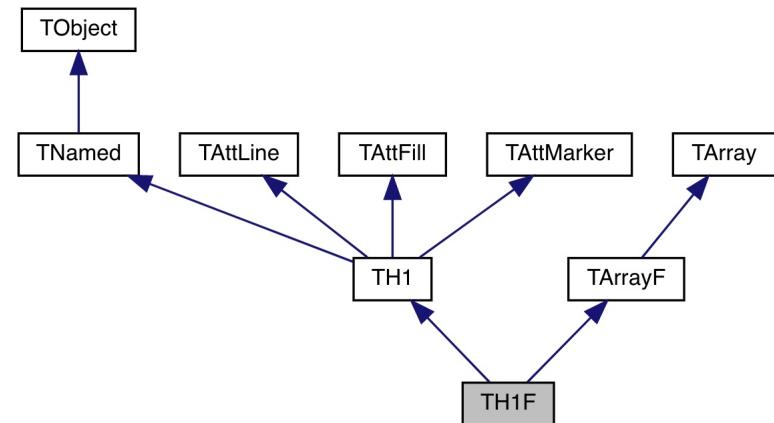
- **class=object** is a combination of data and operations
operation=function=method
- Classes can be part of a hierarchy \Rightarrow Object-Oriented Programming = OOP
 - **Multiple Inheritance** (define only once)



Crash Course in OO Programming

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- 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++

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- 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)7.00000000000000e+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++

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□ 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
```

□ 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]
```

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

```
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

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- 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

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□ 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++

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- 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

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```
#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"
```

C++

```
//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++

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- 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

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- 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

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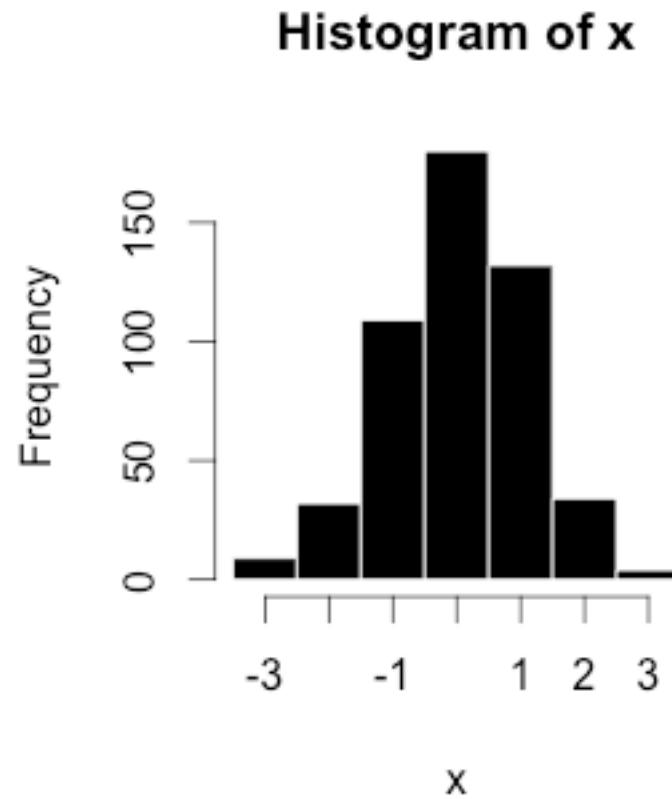
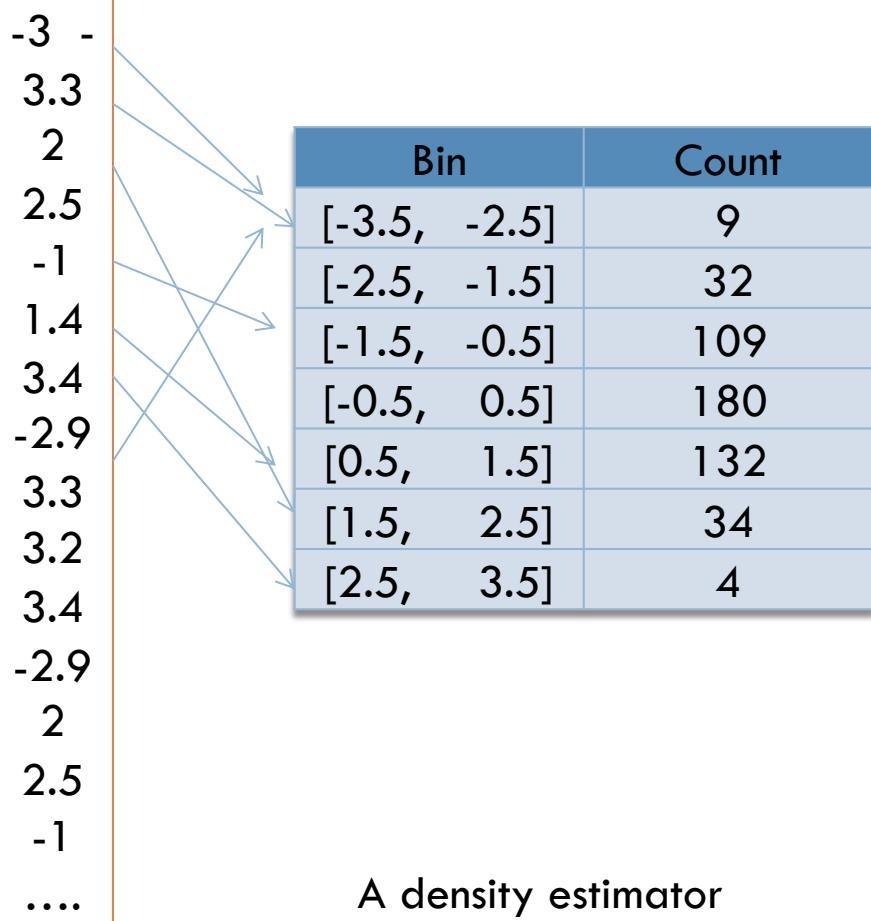
- **TObject:** base class for all ROOT objects
- **TH1:** base class for 1-, 2-, 3-D Histograms
- **TStyle:** class for style of histograms, axis, title, markers, etc...
- **TCanvas:** class for graphical display
- **TGraph:** class of graphic object based on x and y arrays
- **TF1:** base class for 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

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



Histograms in ROOT

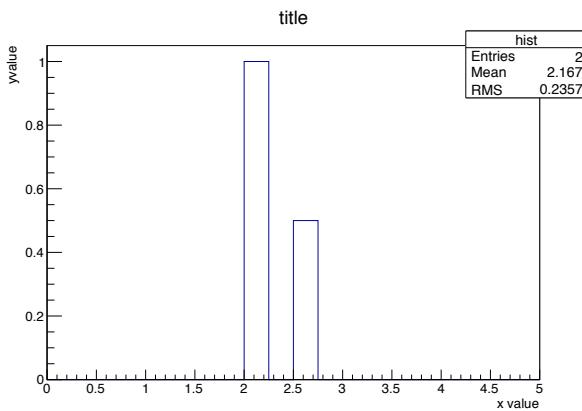
31

❑ Histograms can be:

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

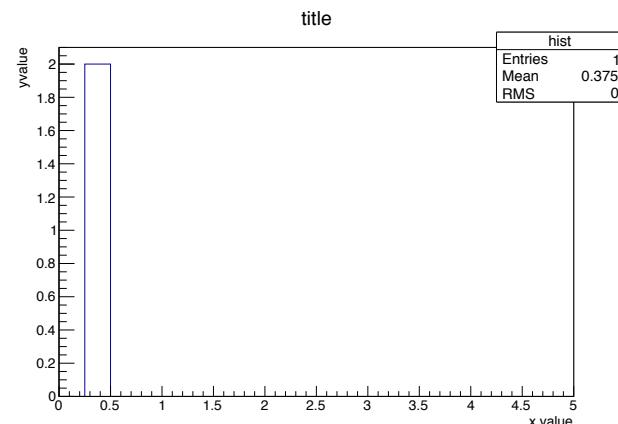
```
>>> from ROOT import TH1F  
>>> hist = TH1F("hist", "title; x value; y value", 20, 0, 5)
```

```
>>> 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

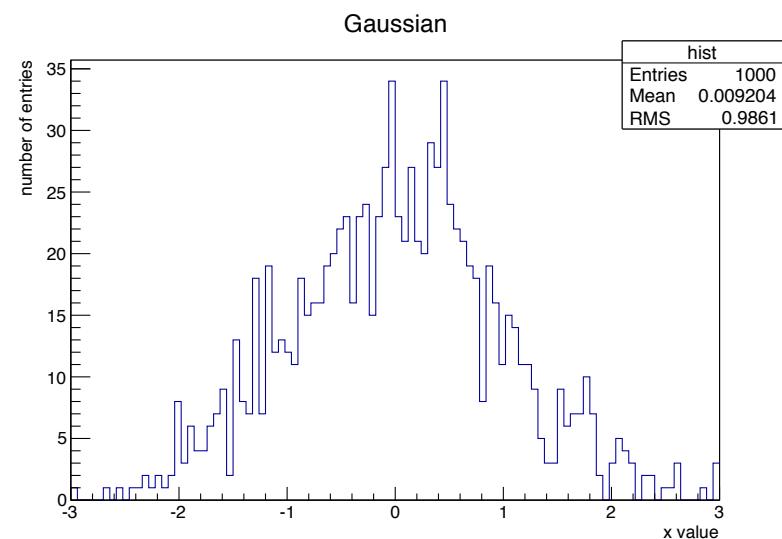
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- Fill histogram according to Gaussian distribution with 1000 entries and extract mean and RMS

```
>>> 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

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```
>>> 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

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Write a python macro ExerciseHist.py

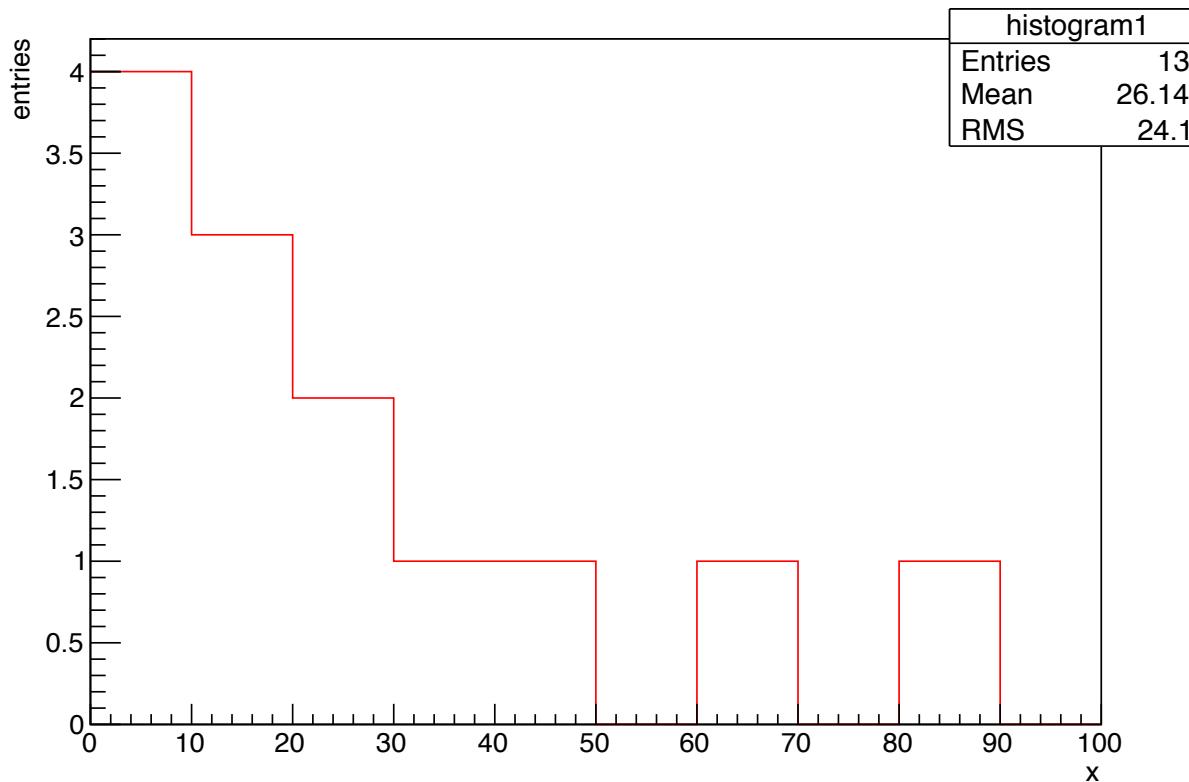
1. Create a histogram with 10 bins ranging from 0. to 100. with title/x-axis label "x"
2. Fill the histogram at the following numbers:
11.3, 25.4, 18.1
3. Fill the histogram with the square of all integers from 0. to 9.
(Hint: A simple loop will save you from typing several lines of code)
4. Draw the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

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<https://root.cern.ch/root/html/doc/guides/users-guide/Histograms.htm>

Canvas and Legends in ROOT

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- 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

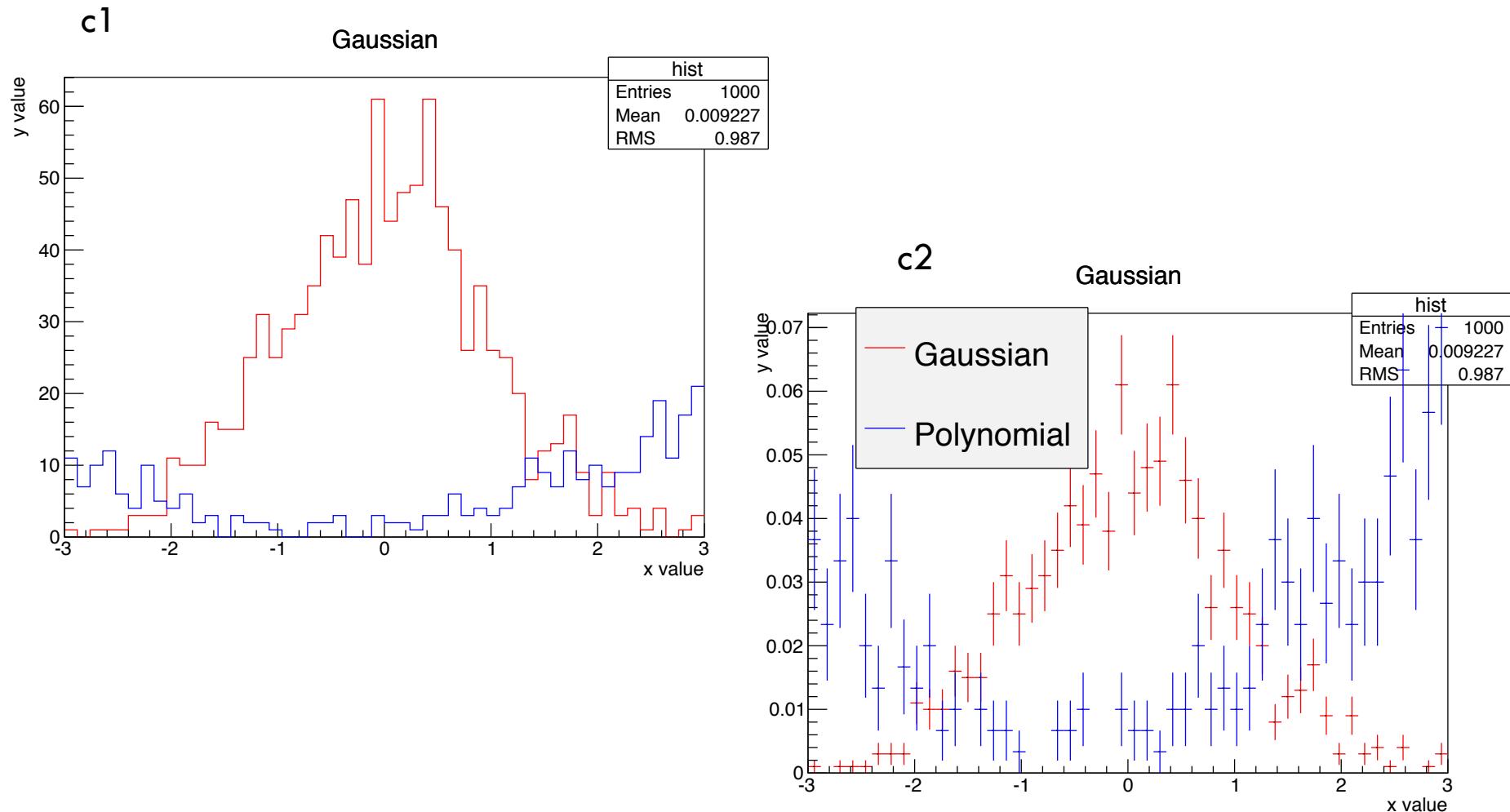
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Write a python macro ExerciseCanvas.py:

- 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

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

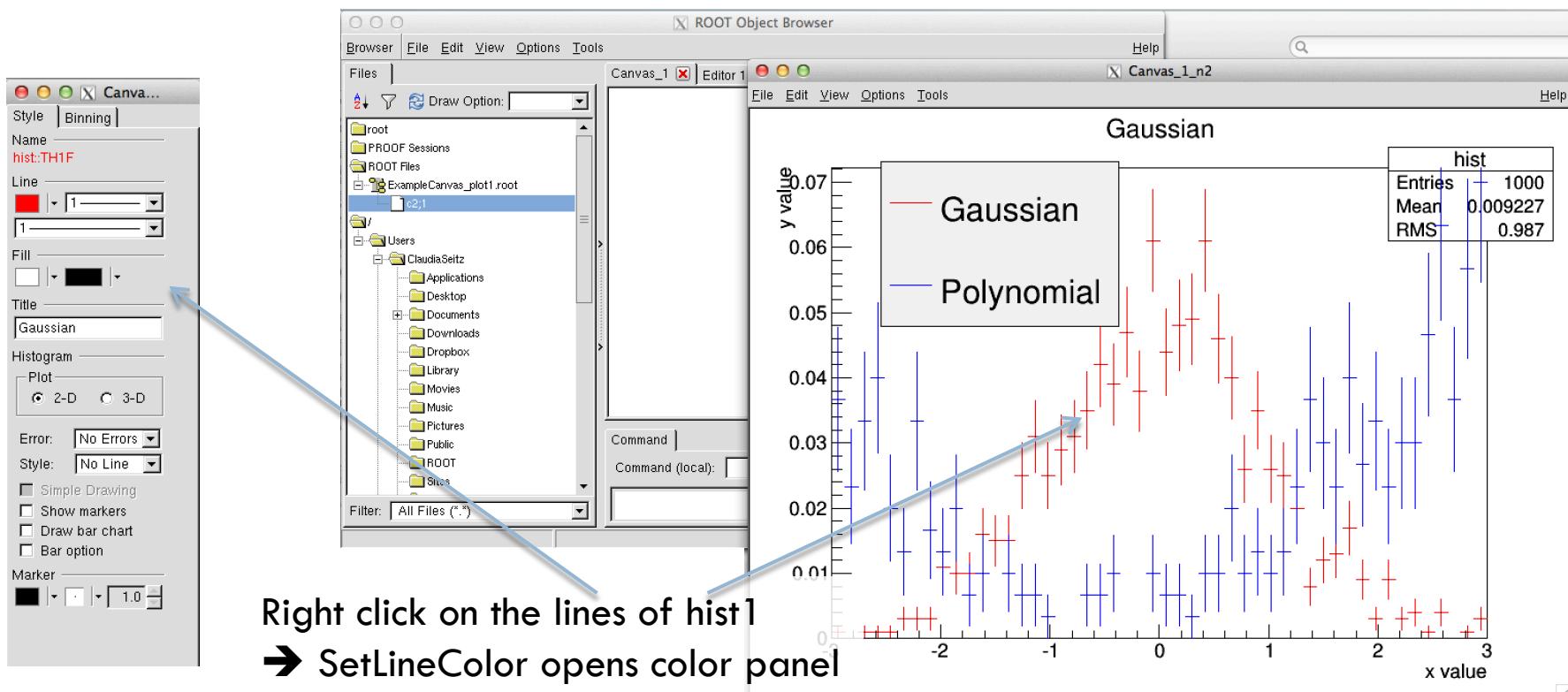
Graphical User Interface (GUI)

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- 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
```



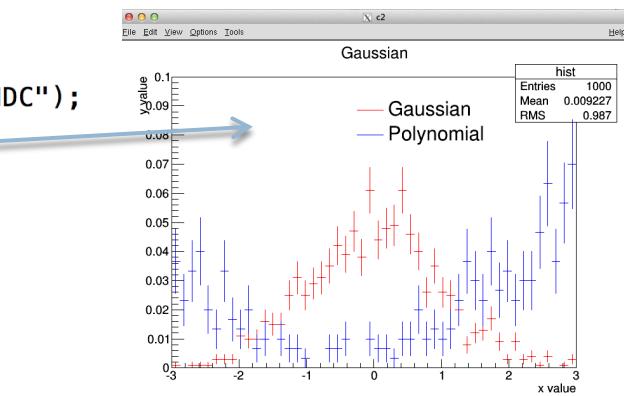
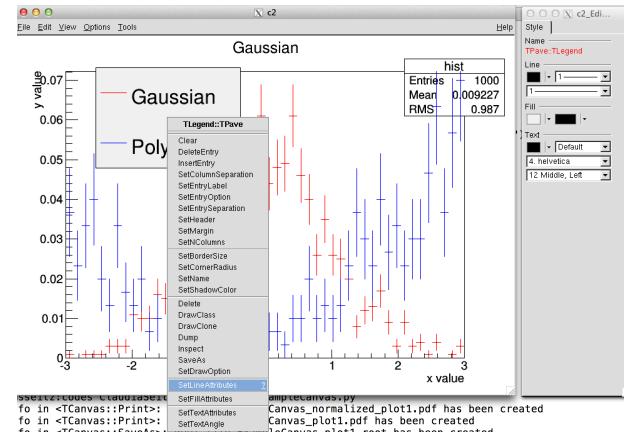
Graphical User Interface (GUI)

40

- 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

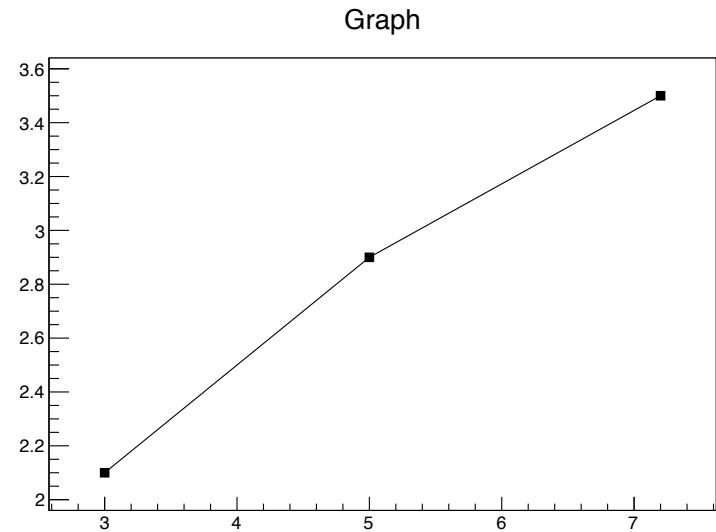


Graphs in ROOT

37

- 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")
```



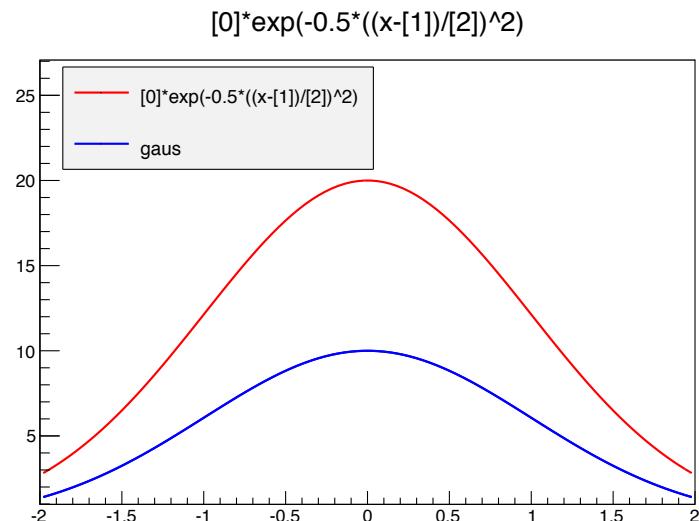
Functions in ROOT

42

□ 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)
```



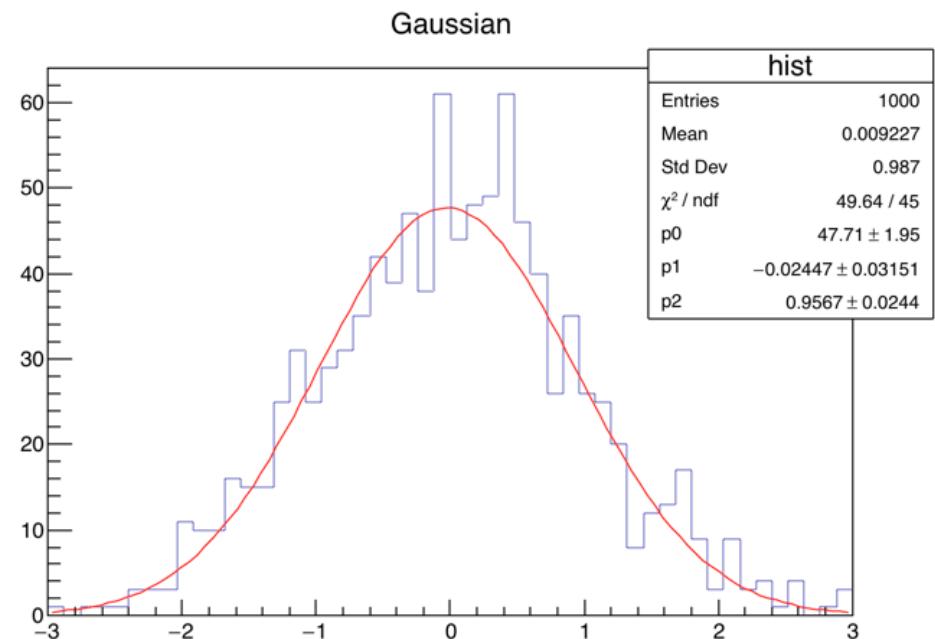
Fitting in ROOT

43

```
>>> 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

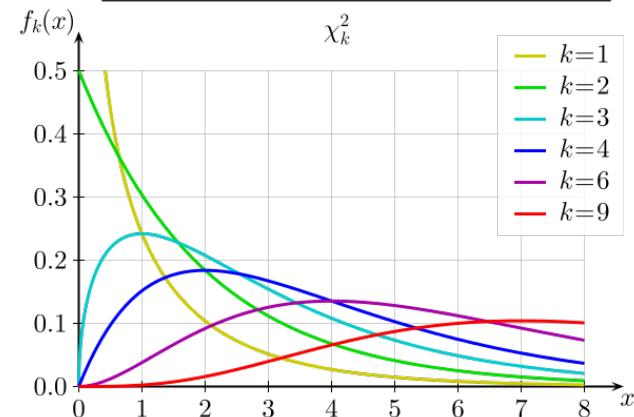
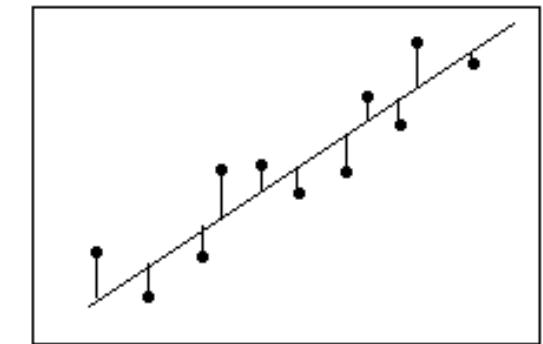


More on Fits and Fitting Quality

44

- 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
 $\text{Gaussian fit } (N, \mu, \sigma) \rightarrow \text{DOF} = 20 - 3$



- <https://root.cern.ch/root/html/doc/guide/users-guide/FittingHistograms.html>

Exercise: Graphs and Fits

45

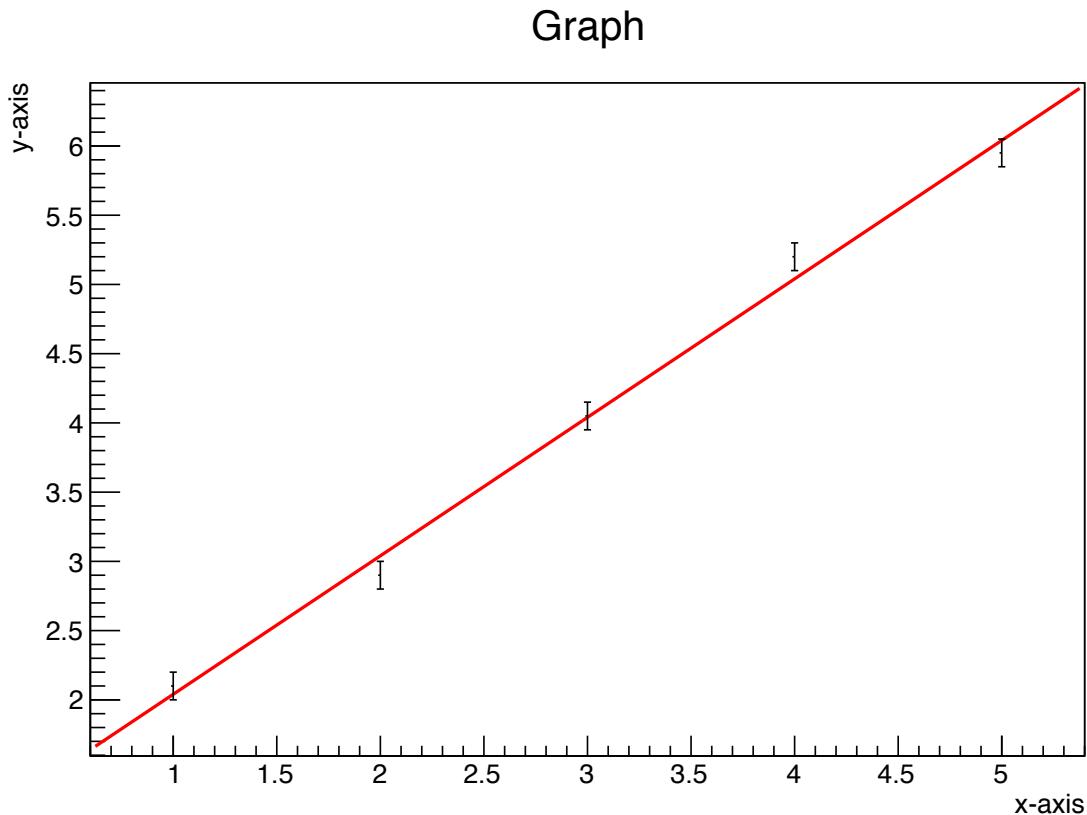
Write a python macro ExerciseGraph.py:

- 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.
- 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\(const char *fname, Option_t *option, Option_t *x, Axis_t xmin, Axis_t xmax\)](#).
 - 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](#).

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

Exercise: Graphs and Fits

46



Classes: TFile and TTree

47

- 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

48

□ 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

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□ 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

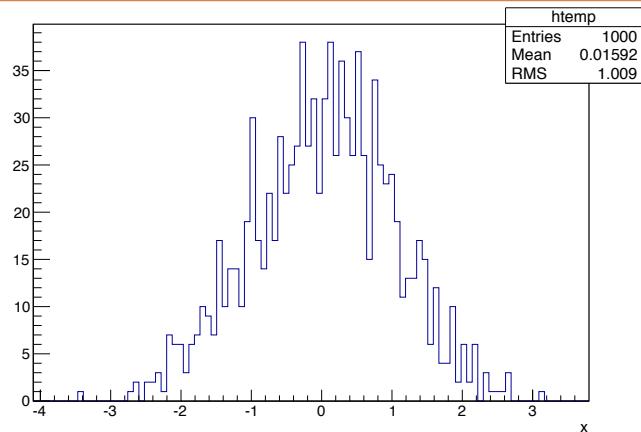
```
>>> t.Scan()  
*****  
* Row * x * y * z *  
*****  
* 0 * -1.102278 * -1.799389 * 4.4528222 *  
* 1 * 1.8671779 * -0.596621 * 3.8423130 *  
* 2 * -0.524181 * 1.8685209 * 3.7661390 *  
* 3 * -0.380611 * 0.9691280 * 1.0840740 *
```

Shows one or multiple
variables for all entries

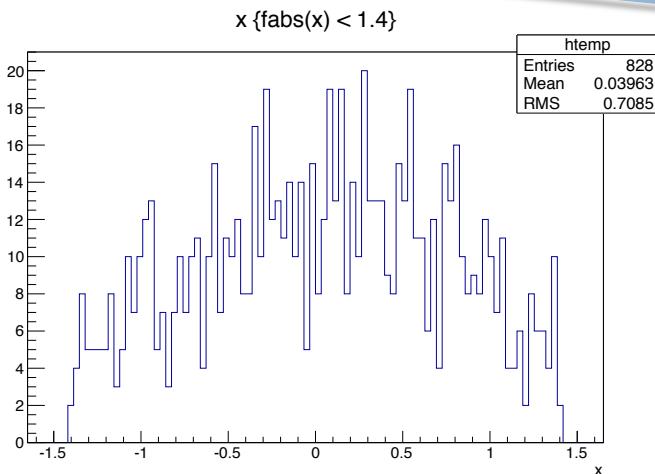
Plotting quantities directly from TTrees

50

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



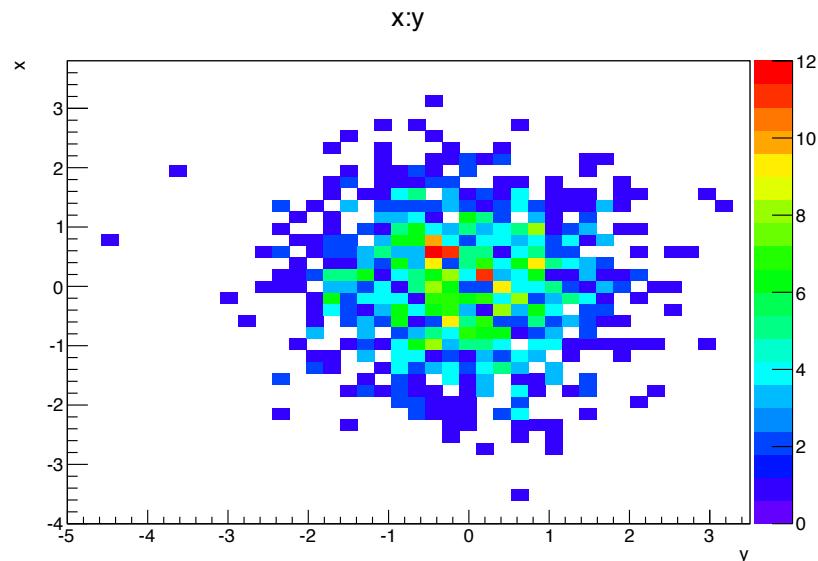
```
>>> t.Draw("x", "fabs(y) < 1.4", "")  
829L
```



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)

51

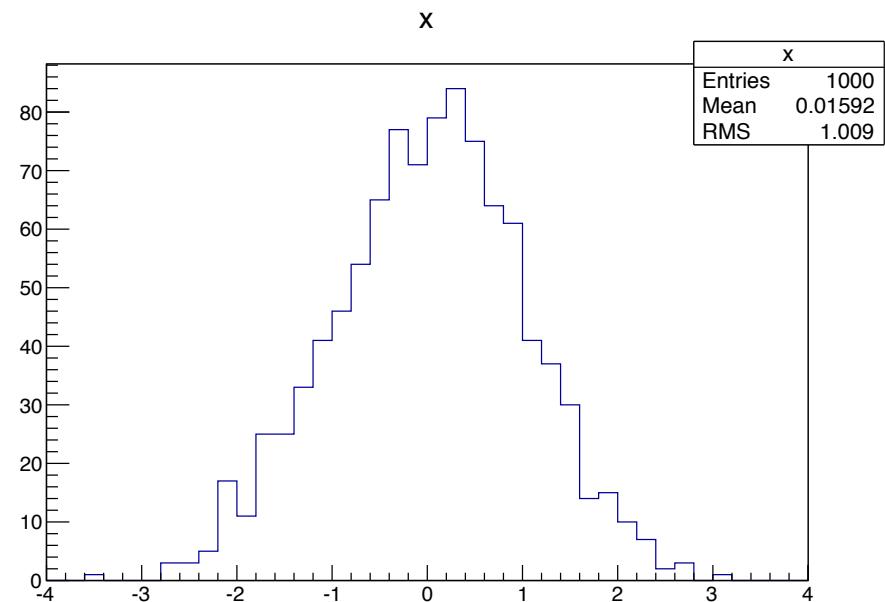
Command	Action
t.Print()	Prints the content of the tree
t.Scan()	Scans the rows and columns
t.Draw("x")	Draw a branch of tree
How to apply cuts: t.Draw("x", "x>0") t.Draw("x", "x>0 && y>0")	Draw "x" when "x>0" Draw "x" when both x >0 and y >0
t.Draw("y", "", "same")	Superimpose "y" on "x"
t.Draw("y:x")	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

52

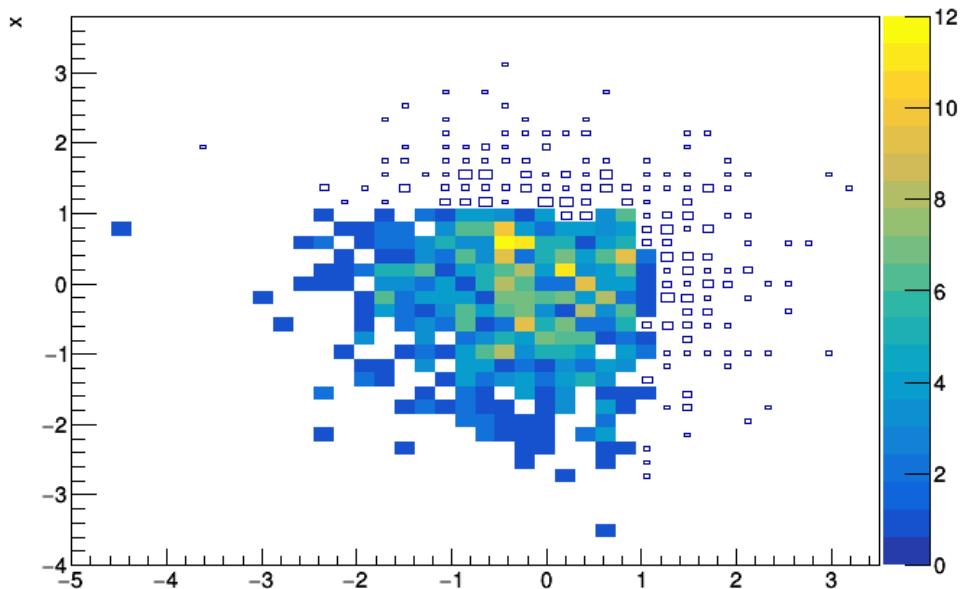
```
>>> from ROOT import TFile,TH1D  
>>> f = TFile("basic.root")  
>>> t = f.Get("ntuple")  
>>> nEntries = t.GetEntries()  
>>> hist = TH1D("x", "x", 40, -4, 4)  
>>> for i in range(0,nEntries):  
...     entry = t.GetEntry(i)  
...     hist.Fill(t.x)  
...  
>>> hist.Draw()
```

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



Draw with Cuts

53



```
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

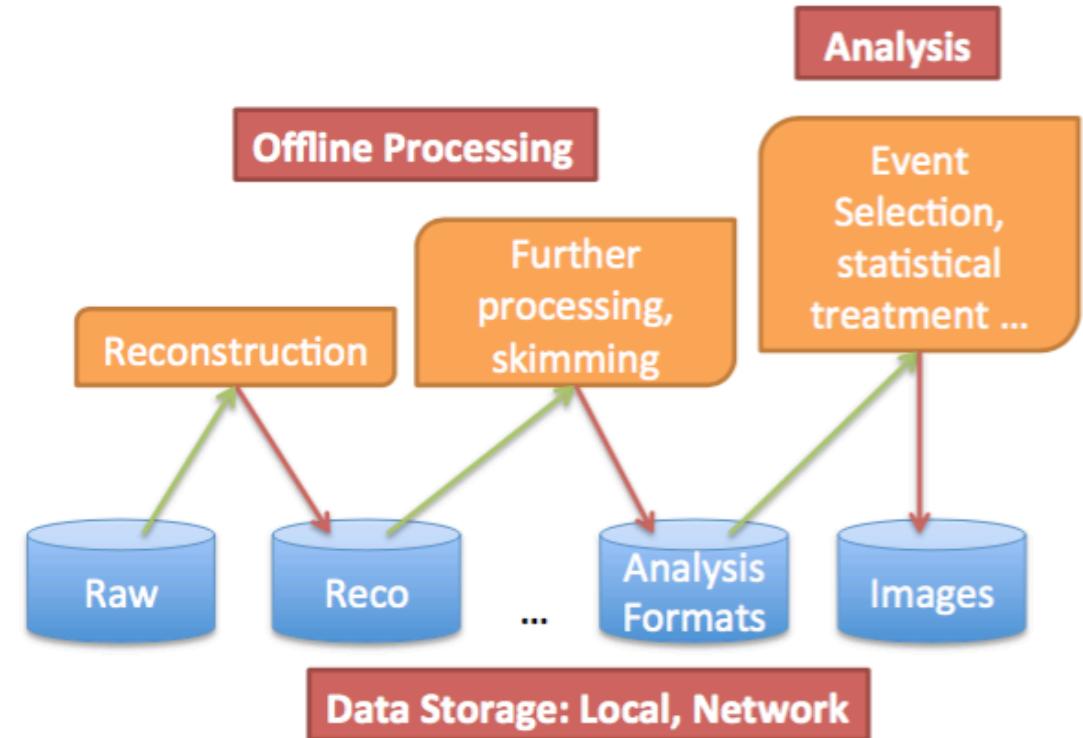
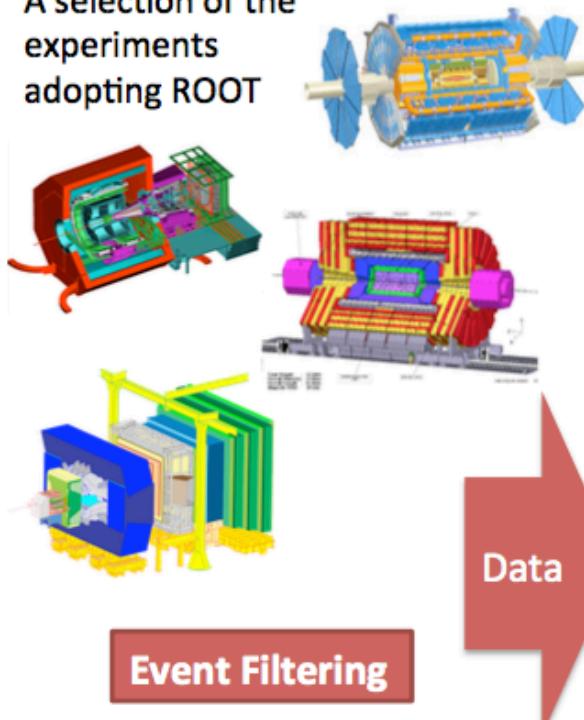
54

- Do p47-p53

Ntuples, Trees and Flat Ntuples

55

A selection of the experiments adopting ROOT



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

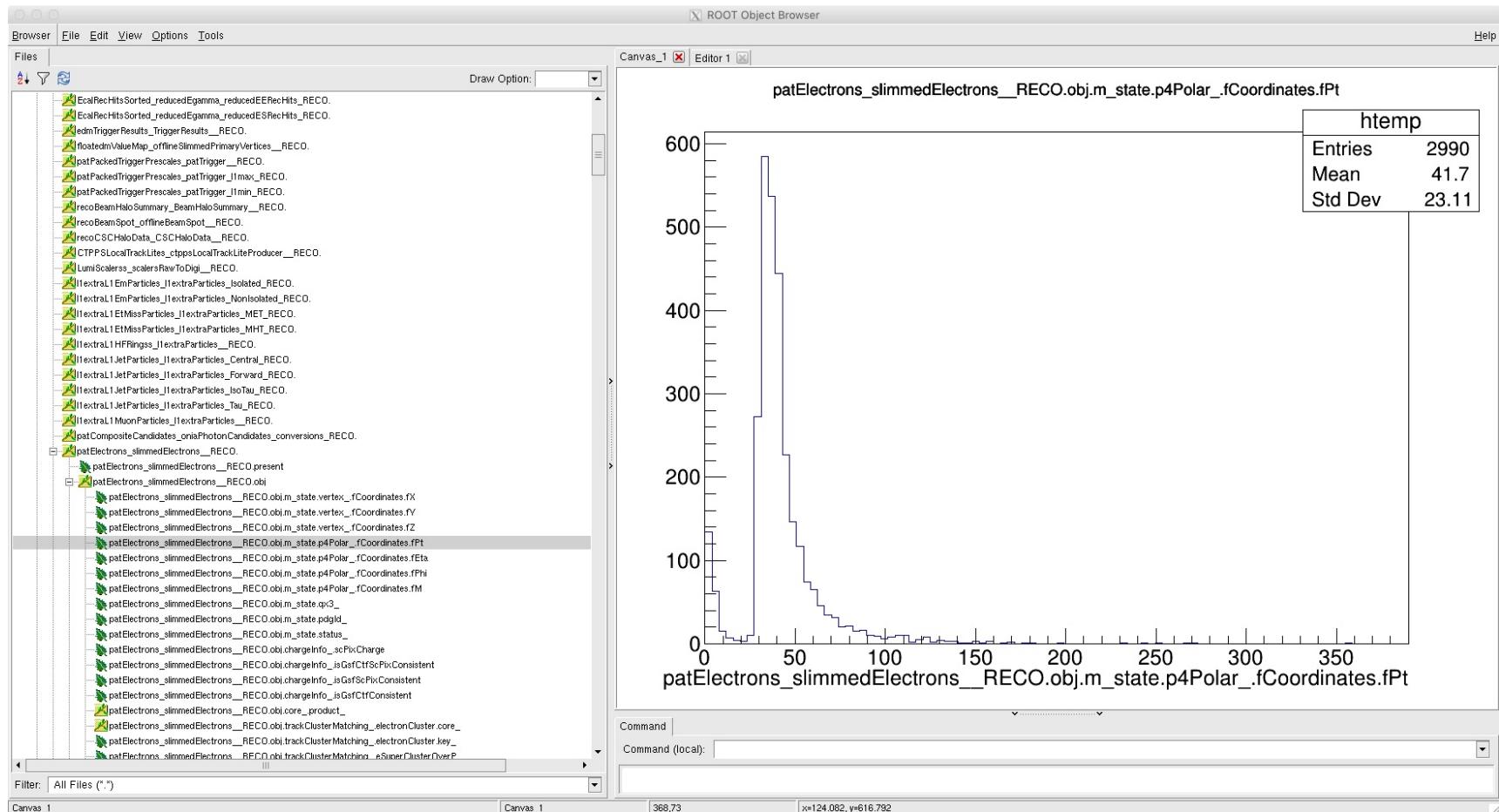
Custom made ntuples

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- 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

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ROOT must know the class definition. This is done within CMSSW
Here we use a simpler example:

Exercise: Custom Made Trees

58

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 stop-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>

You need to read trees with C++?

Check out the TTreeReader

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>