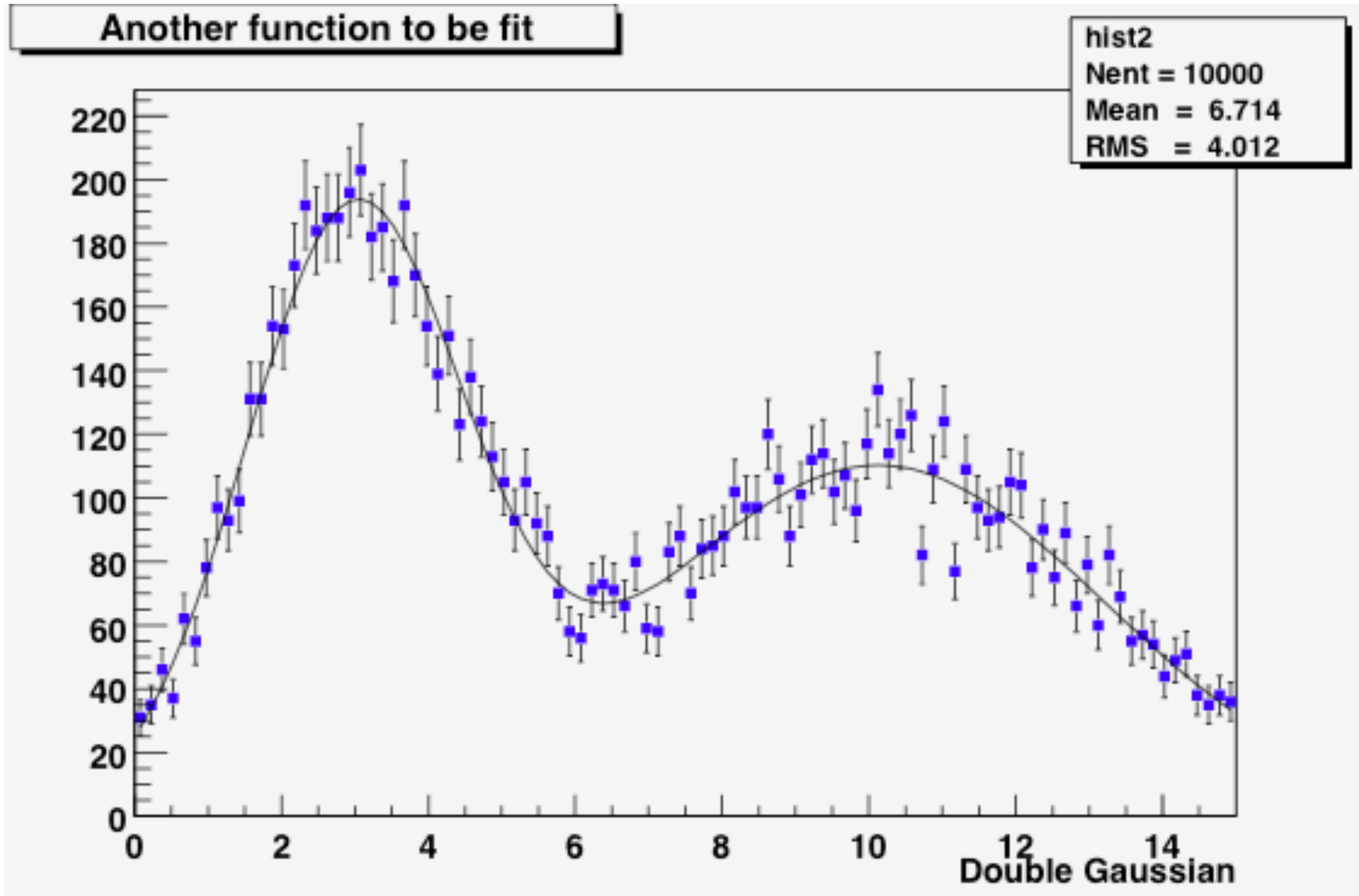
What is ROOT?
Why do we use it?

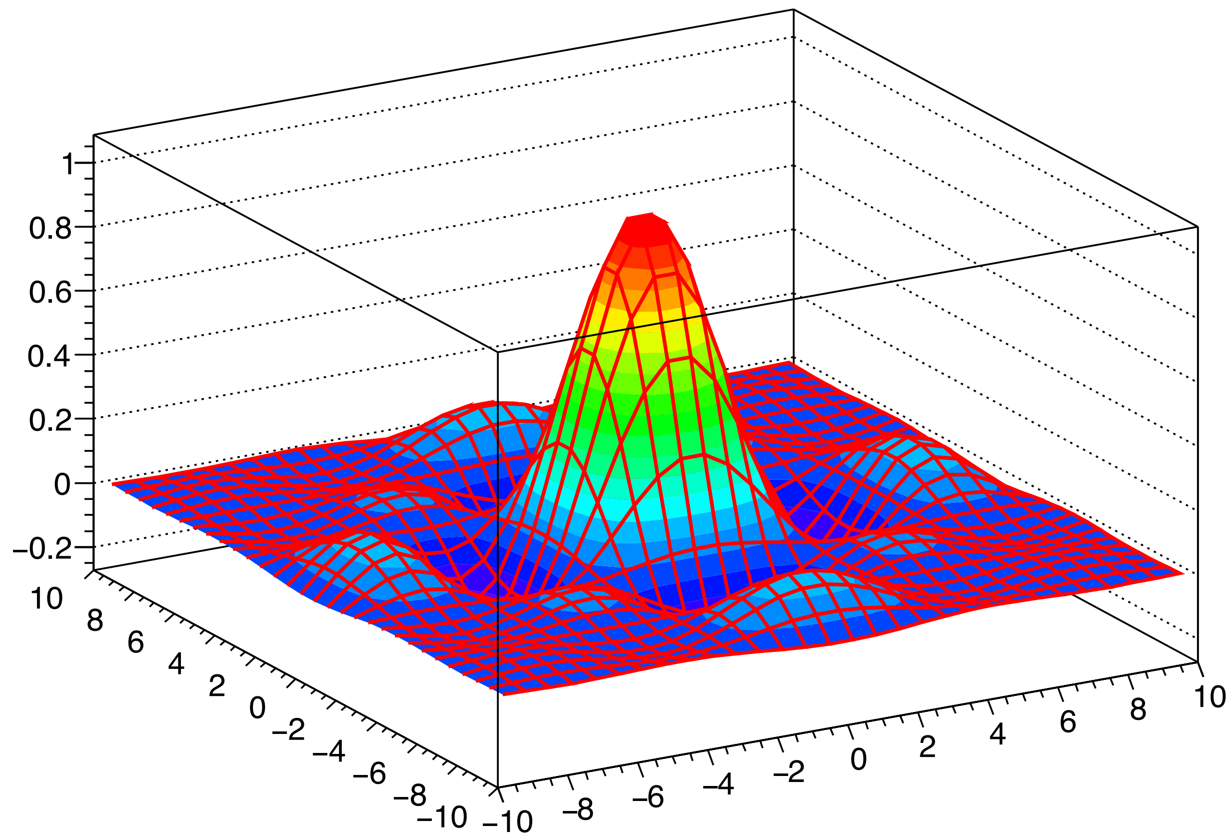
Answer:

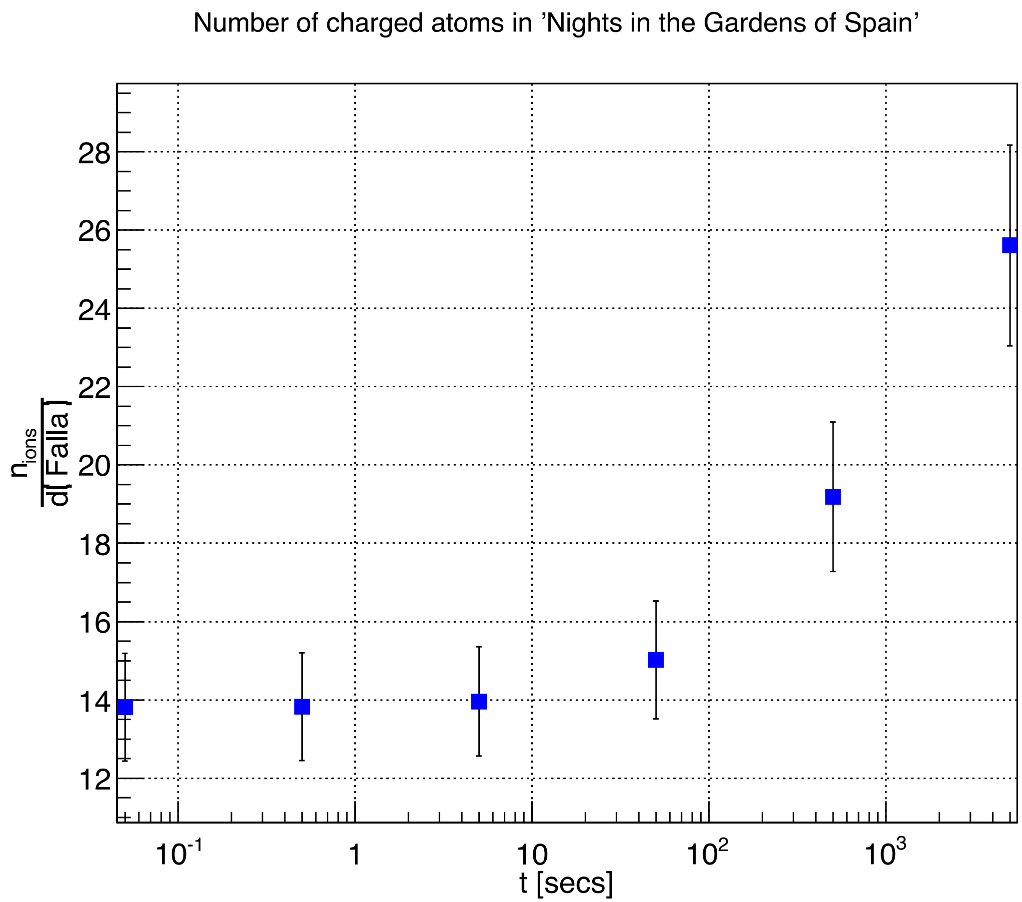
ROOT does what physicists do:

It makes plots.


Another function to be fit
hist2
Nent = 10000
Mean = 6.714
RMS = 4.012
0
20
40
60
80
100
120
140
160
180
200
220
0
2
4
6
8
10
12
14
Double Gaussian

sin(x)*sin(y)/(x*y)





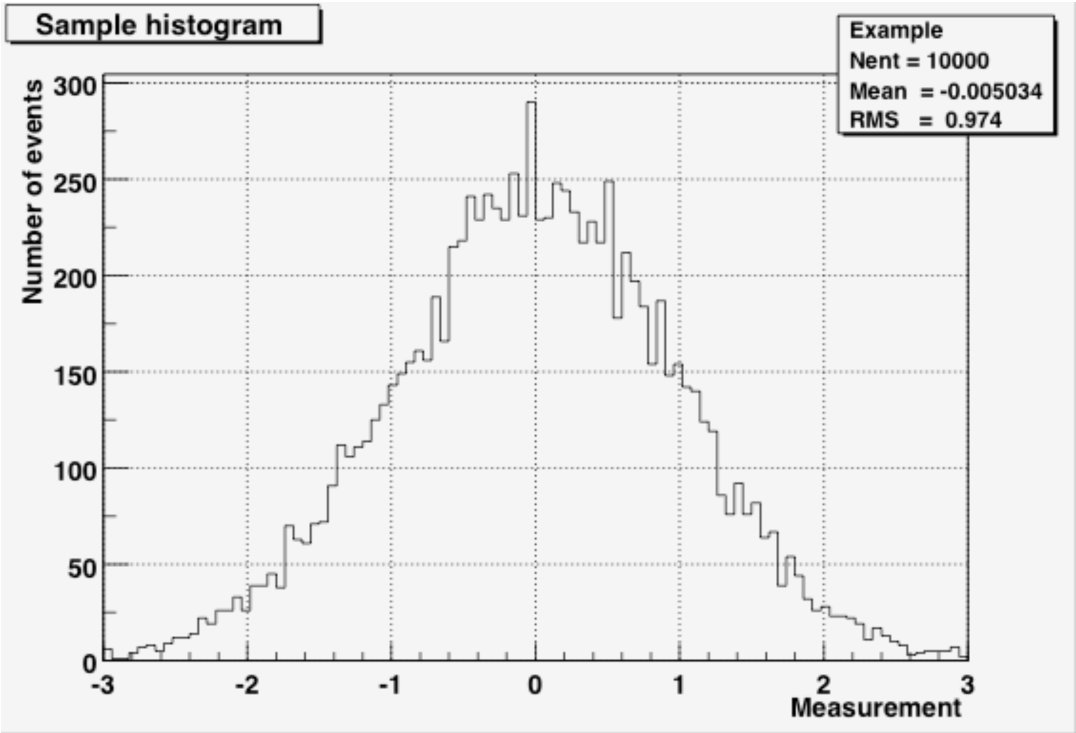
Can you spot the pun in this plot?

The typical analysis task that you will be asked to do:

Take variables in an n-tuple, perform some computations, and make histograms.

So what is a histogram, what is an n-tuple, and how do we perform the computations?

Anatomy of a histogram

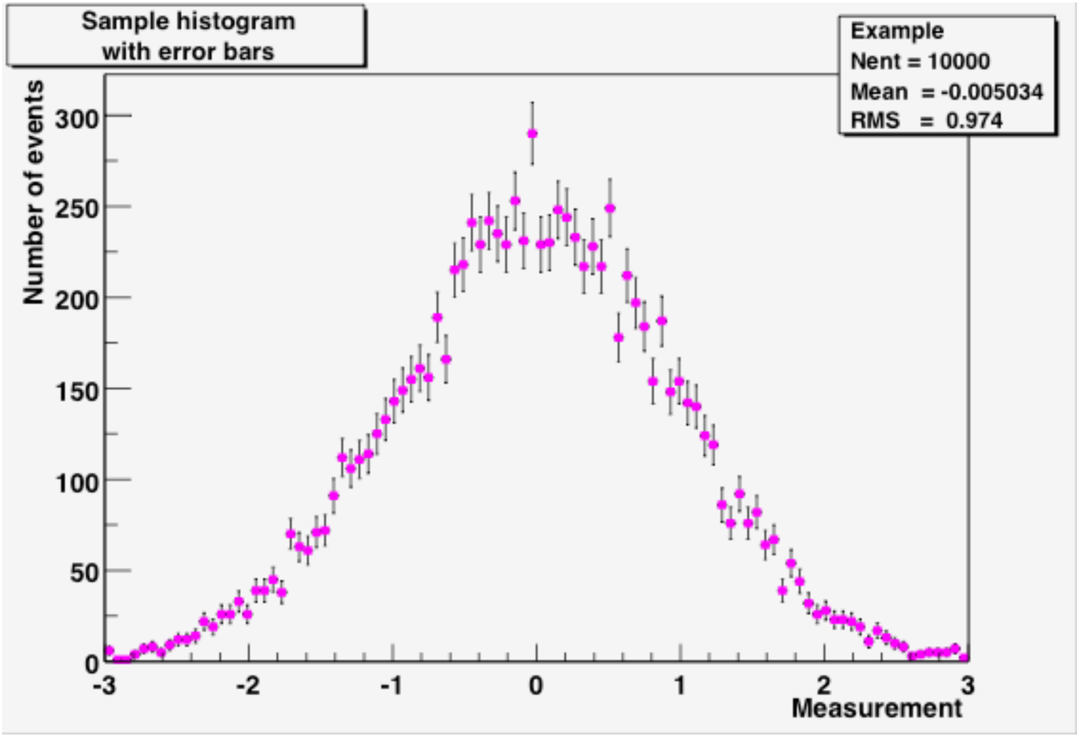


Properties of a histogram

- Name or Identifier
- Title (to be displayed on plot)
- Number of bins
- Lower bin limit
- Upper bin limit

A ROOT command that might be used to define this histogram:

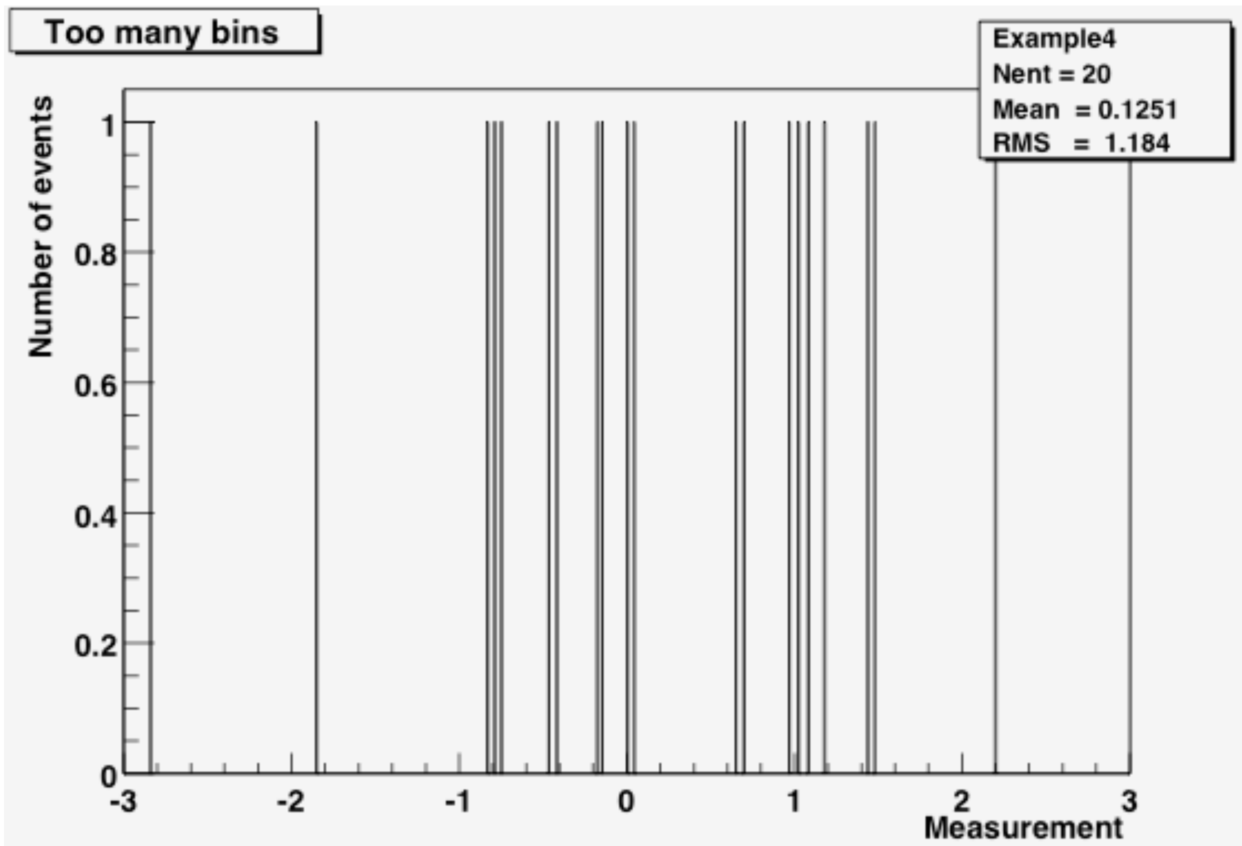
```
TH1F myPlot("Example","Sample histogram",100,-3,3)
```

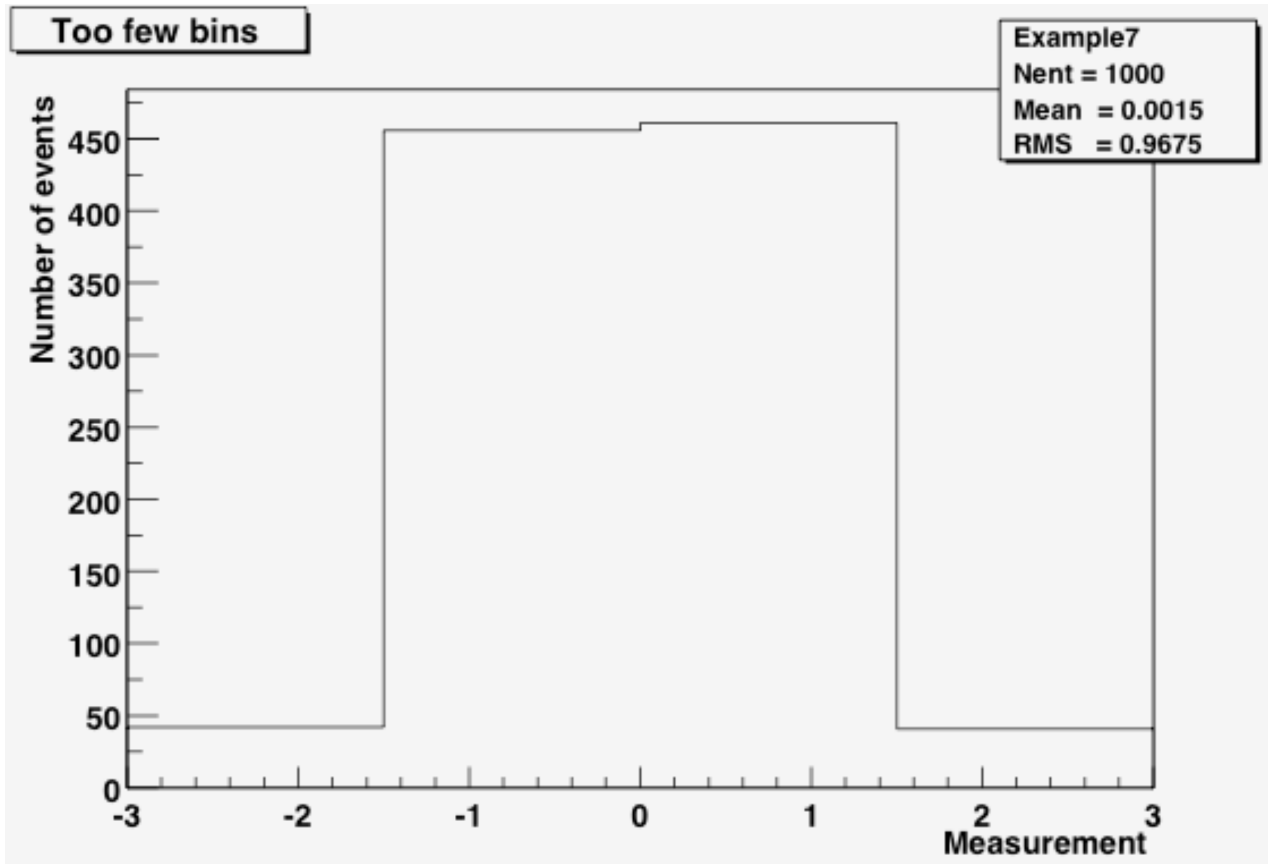


Don't forget the errors!

For simple histograms, the error in one bin is the square root of the number of events in that bin.

There's an art to histogram design...





I found a claim that an optimal number of bins is $\sim\sqrt[3]{N}$, where N is the number of entries in the histogram. I have not substantiated this on my own.

Anatomy of an n-tuple (a simple form of a ROOT Tree)

Branches -->

<-- Entries

Row	event	ebeam	px	py	pz
0	0	150.14	14.33	-4.02	143.54
1	1	149.79	0.05	-1.37	148.60
2	2	150.16	4.01	3.89	145.69
3	3	150.14	1.46	4.66	146.71
4	4	149.94	-10.34	11.07	148.33
5	5	150.18	17.08	-12.14	143.10
6	6	150.02	5.19	7.79	148.59
7	7	150.05	7.55	-7.43	144.45
8	8	150.07	0.23	-0.02	147.78
9	9	149.96	1.21	7.27	146.99
10	10	149.92	5.35	3.98	140.70
11	11	149.88	-4.63	-0.08	147.91

An n-tuple is an ordered list of numbers.

A ROOT Tree can be an ordered list of any collections of C++ objects.

Probably you'll only be asked to work with n-tuples this summer, but in the Expert section of the tutorial you can see what it’s like to work with a ROOT Tree.

Why ROOT?

- It knows about n-tuples and histograms

  and 4-vectors and object persistency and schema evolution
  and detector geometry and Feynmann diagrams
  and linear algebra and function-fitting and multi-variable analysis and…

- It can handle large volumes of data

  millions of physics events; files of gigabytes->terabytes in size; complex file structures; multi-threaded and batch processing

- Multi-platform (Windows, Mac, many UNIX flavors)
- It’s free.
- Some python-based alternatives to ROOT are beginning to show up (e.g., uproot, coffea), but most such alternatives are wrappers around ROOT.
- According to DB experts, HDF5 is good for multi-dimensional arrays used in HPC applications. For every other data structure, ROOT’s file format is generally more efficient.

But...

- ROOT is open-source, with a complicated design history.
- User-interface issues and documentation are often neglected.
- It's not a pre-packaged "app." ROOT is not easy to install.
- "ROOT is not your friend."
- ROOT is pretty much only used in high-energy physics.
- You have to know some C++ in order to use ROOT effectively, in order to perform computations.
- What does C++ look like? Well...

```
#define AnalyzeHistogram_cxx

#include "AnalyzeHistogram.h"
#include <TH2.h>
#include <TStyle.h>

//******** Definition section *********
TH1* chi2Hist = 0;

void AnalyzeHistogram::Begin(TTree * /*tree*/)
{
  TString option = GetOption();

  //******** Initialization section *********
  chi2Hist = new TH1F("chi2","Histogram of Chi2",100,0,20);
  chi2Hist->GetXaxis()->SetTitle("chi2");
  chi2Hist->GetYaxis()->SetTitle("number of events");
}

void AnalyzeHistogram::SlaveBegin(TTree * /*tree*/)
{
  TString option = GetOption();
}

Bool_t AnalyzeHistogram::Process(Long64_t entry)
{
  //******** Loop section *********
  tree1->GetEntry(entry);
  chi2Hist->Fill(chi2);

  return kTRUE;
}

void AnalyzeHistogram::SlaveTerminate()
{}

void AnalyzeHistogram::Terminate()
{
  //******** Wrap-up section *********
  chi2Hist->Draw();
}
```

If you prefer Python, there's pyroot

```
import ROOT

# Open the file.
myfile = ROOT.TFile( 'experiment.root' )

# Retrieve the n-tuple of interest.
mychain = ROOT.gDirectory.Get( 'tree1' )
entries = mychain.GetEntriesFast()

# Create a 2D histogram
myHist = ROOT.TH2D("hist2D","chi2 vs ebeam",100,0,20,100,149,151)
myHist.GetXaxis().SetTitle("chi2")
myHist.GetYaxis().SetTitle("ebeam [GeV]")

for jentry in xrange( entries ):

   # Copy next entry into memory and verify.
   nb = mychain.GetEntry( jentry )
   if nb <= 0:
      continue

   # Fetch the variables from the entry and fill the histogram.
   chi2 = mychain.chi2
   ebeam = mychain.ebeam
   myHist.Fill(chi2,ebeam)

# Display the scatterplot.
myHist.Draw()
```

Web Links

All the documents you've seen (and will see) during these tutorial sessions can be found here (this is the *only* link you need to write down from this lecture):

https://www.nevis.columbia.edu/~seligman/root-class/

ROOT and C++ links, including links to reference books on C++ and statistics, can be found at:

http://www.nevis.columbia.edu/~seligman/root-class/links.html

The Hands-on Course

Basic Data Analysis using ROOT

ROOT basics

Over the next 2-3 days, you will learn how to:

- look up ROOT command references
- plot a function
- histogram a variable
- fit a histogram
- get a variable from an n-tuple
- apply cuts
- do a quick study using TreeViewer (optional)
- create C++ or python code or use RDataFrame on an n-tuple
- use the Jupyter notebook server for quick coding

-- but not necessarily in this order!

Wait… there's more!

The written tutorial includes intermediate topics, advanced topics, and an appendix. They're there if you have the time during the tutorial sessions, or for reference later on as you work with ROOT.

Intermediate topics include:

- Advanced histogram techniques
- How to install ROOT on your laptop (if you must)

Advanced ROOT, and becoming a ROOT expert:

- Creating an x-y plot
- Working with large numbers of histograms
- Extracting your own n-tuples

The appendix includes:

- Statistics jargon that physicists use
- Programming tips
- Batch systems

A Brief ROOT Demonstration

- Using the command line
- Using the notebook server