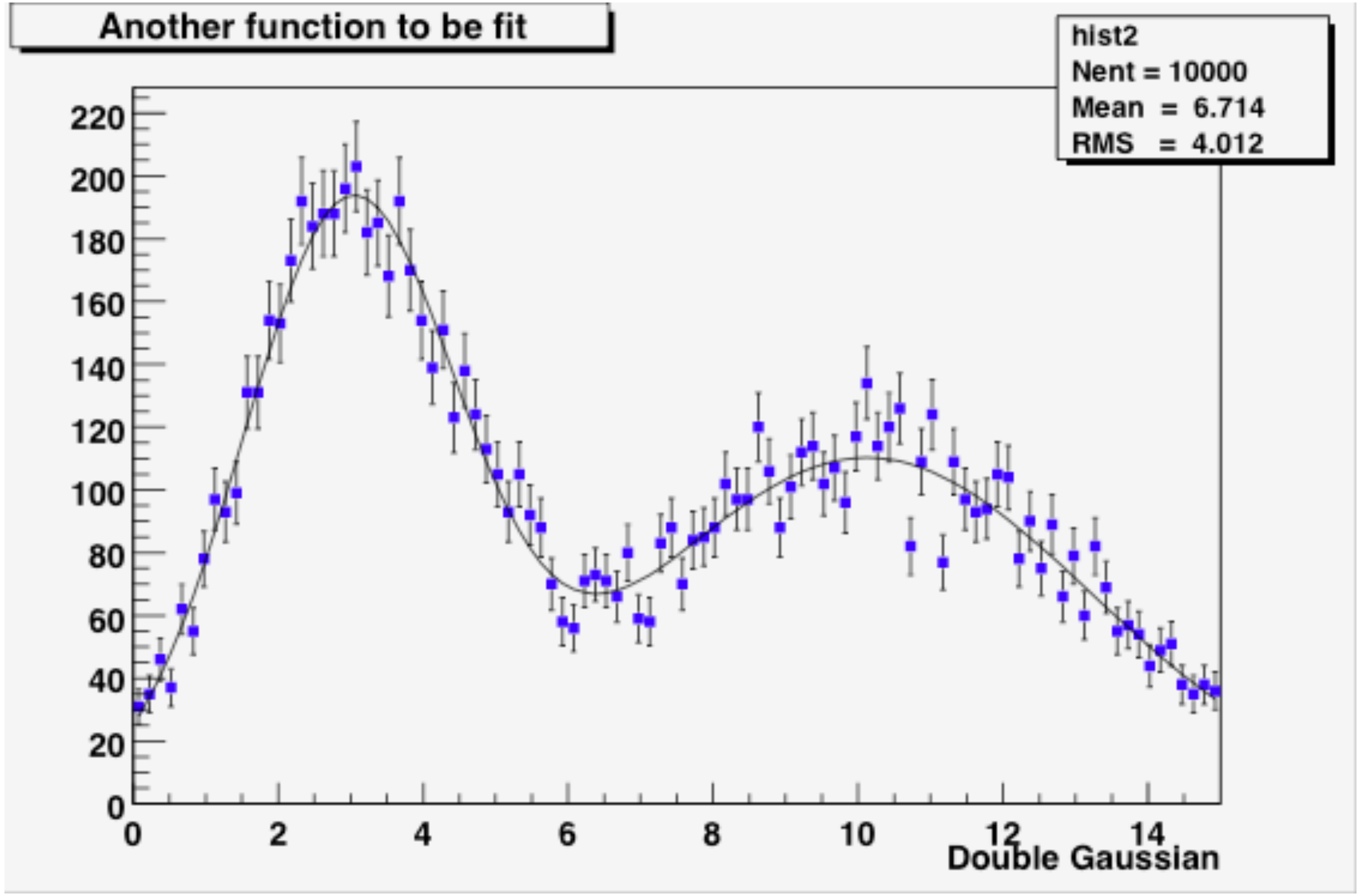
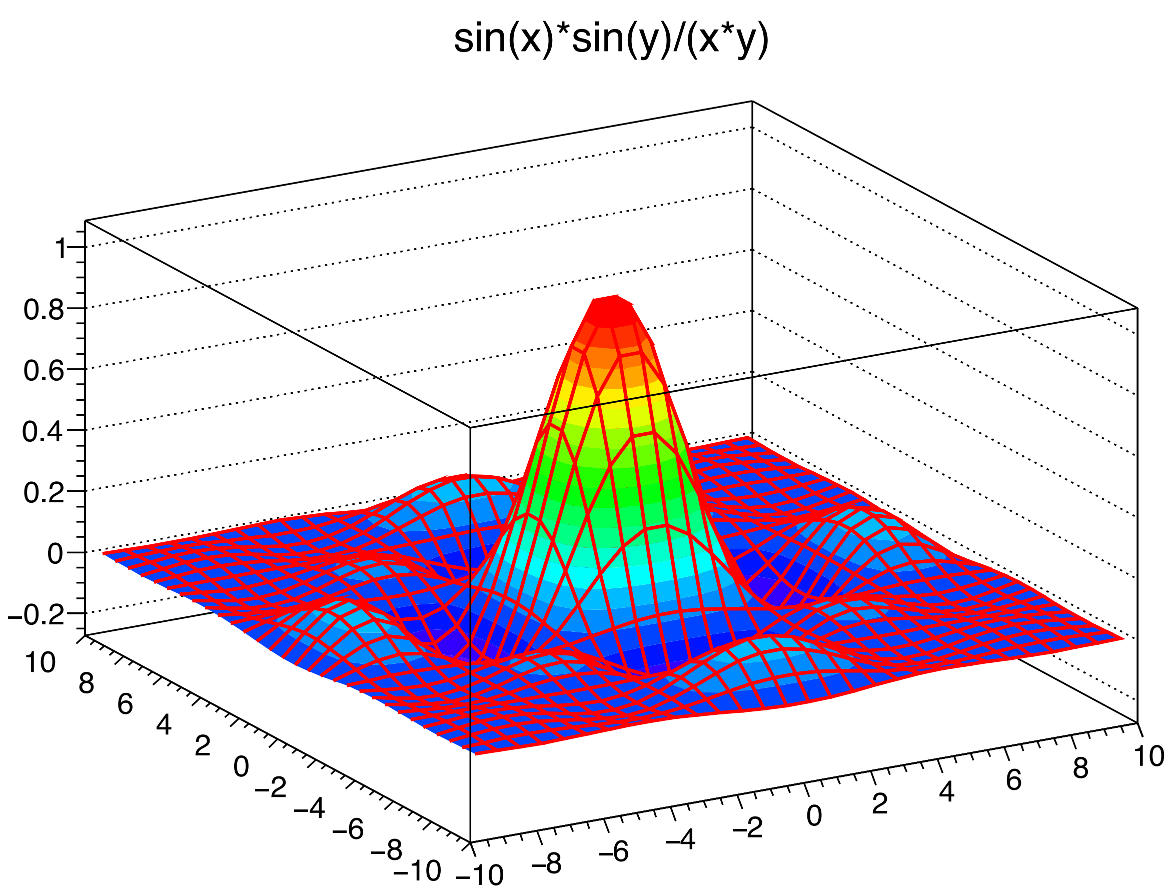
What is ROOT?
Why do we use it?

Answer:

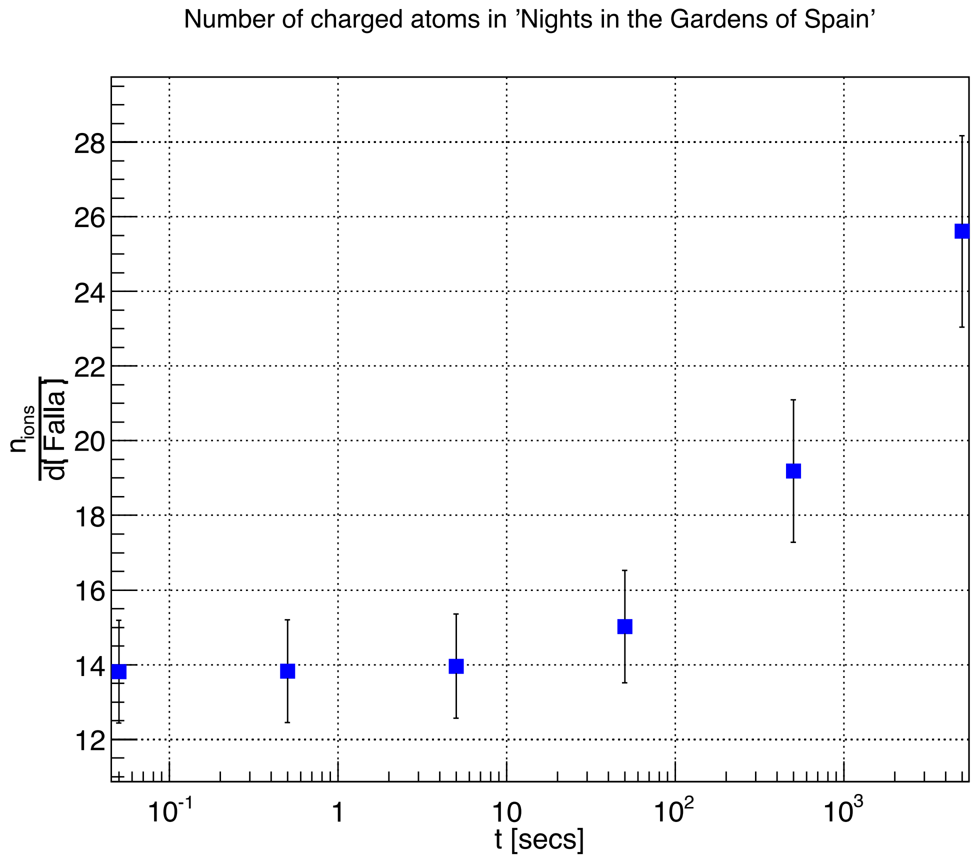
ROOT does what physicists do:

It makes plots.


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



sin(x)*sin(y)/(x*y)
1
0.8
0.6
0.4
0.2
0
−0.2
10
8
6
4
2
0
−2
−4
−6
−8
−10
−10
−8
−6
−4
−2
0
2
4
6
8
10



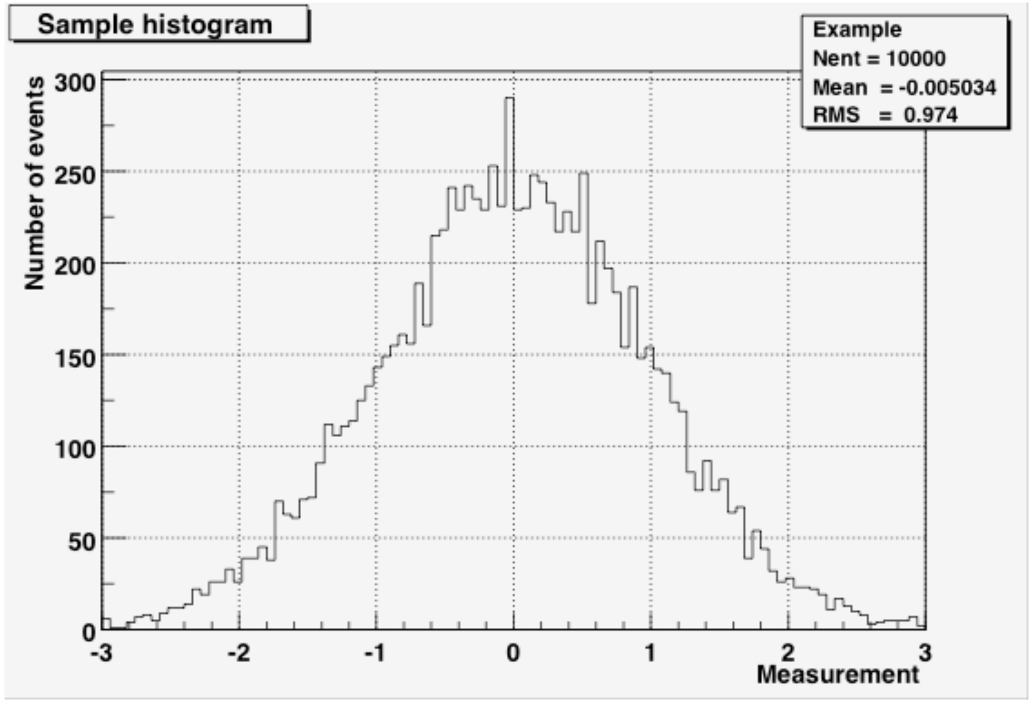
Can you spot the pun in this plot?

A basic analysis task that you could 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

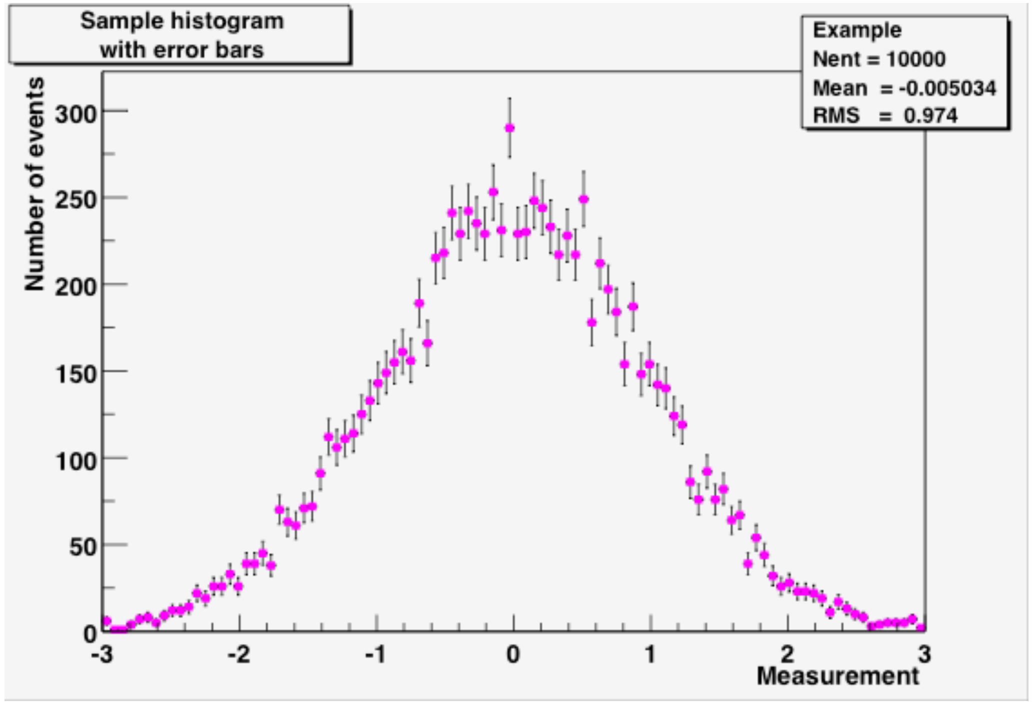


Properties of a histogram

- 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.

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 (and in the appendix) you can see what it’s like to work with a ROOT Tree.

Computation: A typical physics analysis task consists of:

Set-up → Initialize values, define objects, etc.

Event Loop → For each row in the table (or "for each entry in the n-tuple"), do something:

> Typically this is some form of data manipulation or reduction (e.g., include a new value in a histogram)

Wrap-up → Save and show results

TreeViewer, RDataFrame, and C++ macros are among the ROOT tools that can automate this process.

Why ROOT?

- The histogram is a fundamental data reduction tool in high-statistics physics analyses.
- In physics, the n-tuple is a fundamental data format that's the result of, and the source for, histograms.
- The event loop (for example, "filling a histogram") is a fundamental computation in the final steps of a physics analysis.
- ROOT provides tools to support and automate these steps.
  Examples:
  - histogram arithmetic (with correct propagation of errors);
  - merging, chaining, and updating n-tuples;
  - interactive C++ interfaces and functions to perform complex computations;
  - Python bindings to enable C++ functionality with the interpreted environment.

What is ROOT?
Why do we use it?

Answer:

ROOT does what physicists do:

It makes plots **in a way that seems natural to them.**

Wait… there's more!

- ROOT contains a wide range of tools for data analysis

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

- It can handle large volumes of data

  billions → trillions of physics events; files of terabytes → petabytes in size; complex file structures; multi-threaded and batch processing

- Multi-platform (Windows, Mac, most UNIX flavors)
- It’s free.
- Some python-based alternatives to ROOT exist (e.g., uproot, coffea), but most such alternatives are wrappers around ROOT.
- According to database experts, HDF5 is good for multi-dimensional arrays used in HPC applications. For other data structures associated with physical sciences, 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.
- 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()
```

The Hands-on Course

Basic Data Analysis using ROOT

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)
- use the Jupyter notebook server for quick coding
- woth with an n-tuple using C++, python, or RDataFrame

-- 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 in physics.

Intermediate topics include:

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

Advanced ROOT, and becoming a ROOT expert:

- Working with large numbers of histograms
- Extracting your own n-tuples

The appendices include:

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

What I won't teach you

- C++
- Python

I'm well-aware that some of the PIs in the groups are under the impression that I can teach an entire programming language in just 2-3 days.

At most you'll learn a bit about syntax; e.g.,:

- defining a variable
- writing a loop
- `if` statements

If programming is completely new to you, or you know that your research group does not use ROOT, take the RDataFrame path. You'll learn some techniques that will hopefully be useful for the analysis tools in your field of study.

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 my lectures)

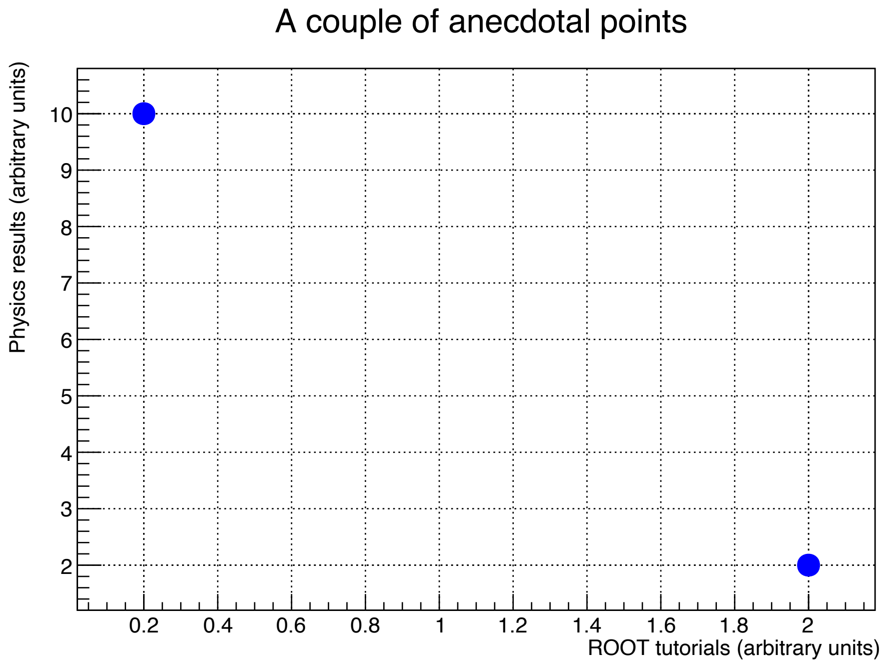
https://www.nevis.columbia.edu/~seligman/root-class/

Links to references on ROOT, C++, and statistics, can be found at:

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

A Brief ROOT Demonstration

- Using the command line
- Using the notebook server


A couple of anecdotal points
Physics results (arbitrary units)
ROOT tutorials (arbitrary units)