Introduction to ROOT
Practical Session

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IFIC Summer Student 2017

July 10th 2016

ROOT
Data Analysis Framework

Practical introduction to the ROOT framework

- Starting ROOT
- Macros
- Functions
- Histograms
- Files
- TTrees
- TBrowser
- Pyroot

Macros and slides are in :
http://cern.ch/go/j8PV

ROOT in a Nutshell

- *ROOT is a large Object-Oriented data handling and analysis framework*
  - *Efficient object store scaling from kB's to PB's C++ interpreter*
- *Extensive 2D+3D scientific data visualization capabilities*
- *Extensive set of multi-dimensional histograming, data fitting, modeling and analysis methods*
- *Complete set of GUI widgets*
- *Classes for threading, shared memory, networking, etc.*
- *Parallel version of analysis engine runs on clusters and multi-core*
- *Fully cross platform: Unix/Linux, MacOS X and Windows*

ROOT in a Nutshell (2)

- *The user interacts with ROOT via a graphical user interface, the command line or scripts*
- *The command and scripting language is C++*
  - *Embedded C++ interpreter CINT (ROOT5)/ CLING (ROOT6)*
  - *Large scripts can be compiled and dynamically loaded*

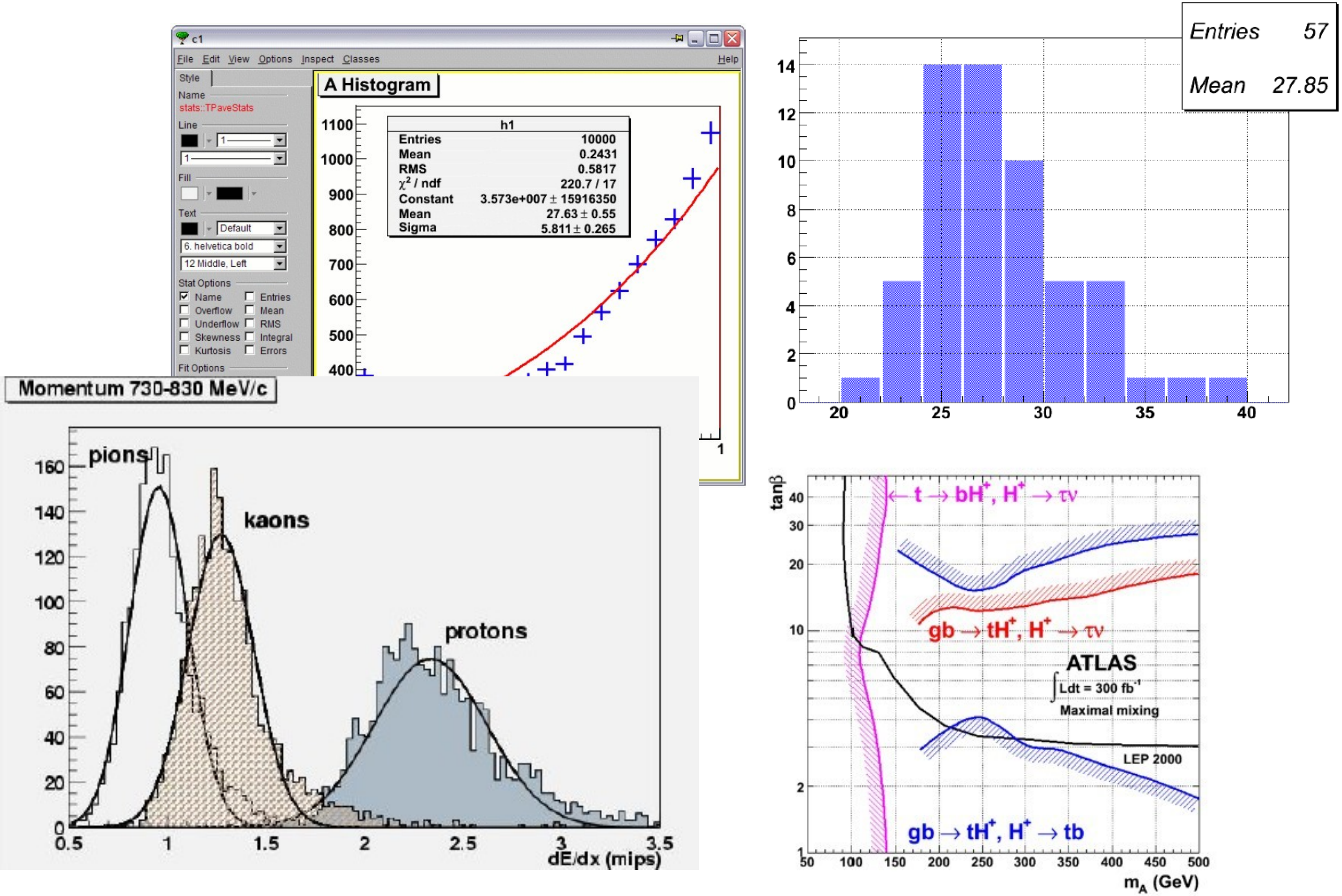
… but for you?

ROOT is usually the interface (and sometimes the barrier) between you and the data

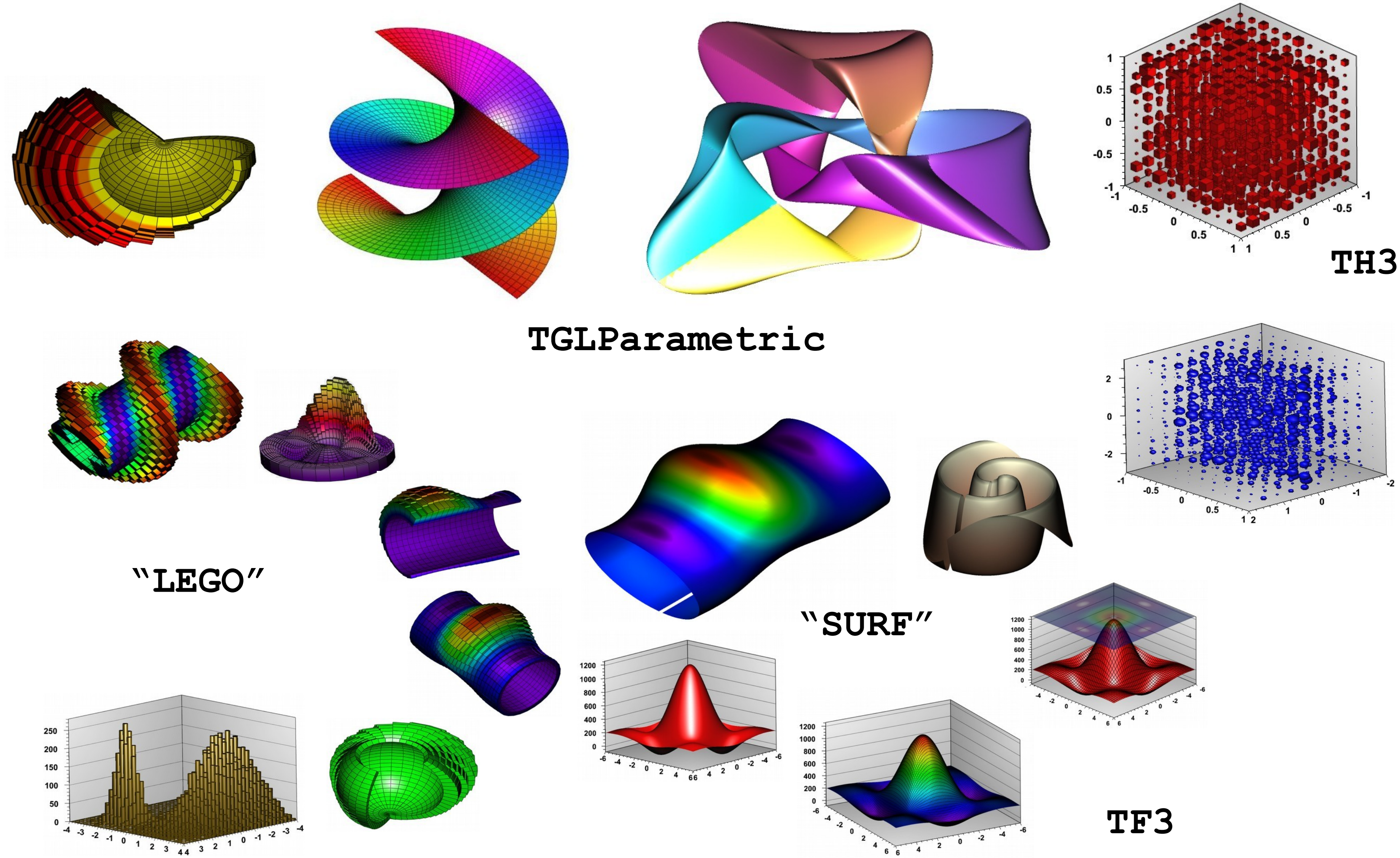
ROOT an Open Source Project

- *The project was started in Jan 1995. First release Nov 1995. The project is developed as a collaboration between:*
  - *Full time developers:*
  - *7 people full time at CERN (PH/SFT)*
  - *2 developers at Fermilab/USA*
- *Large number of part-time contributors (160 in CREDITS file)*
- *A long list of users giving feedback, comments, bug fixes and many small contributions*
  - *5,500 users registered to RootTalk forum*
  - *10,000 posts per year*
- *An Open Source Project, source available under the LGPL license*
- *Used by all major HEP experiments in the world*
- *Used in many other scientific fields and in commercial world.*

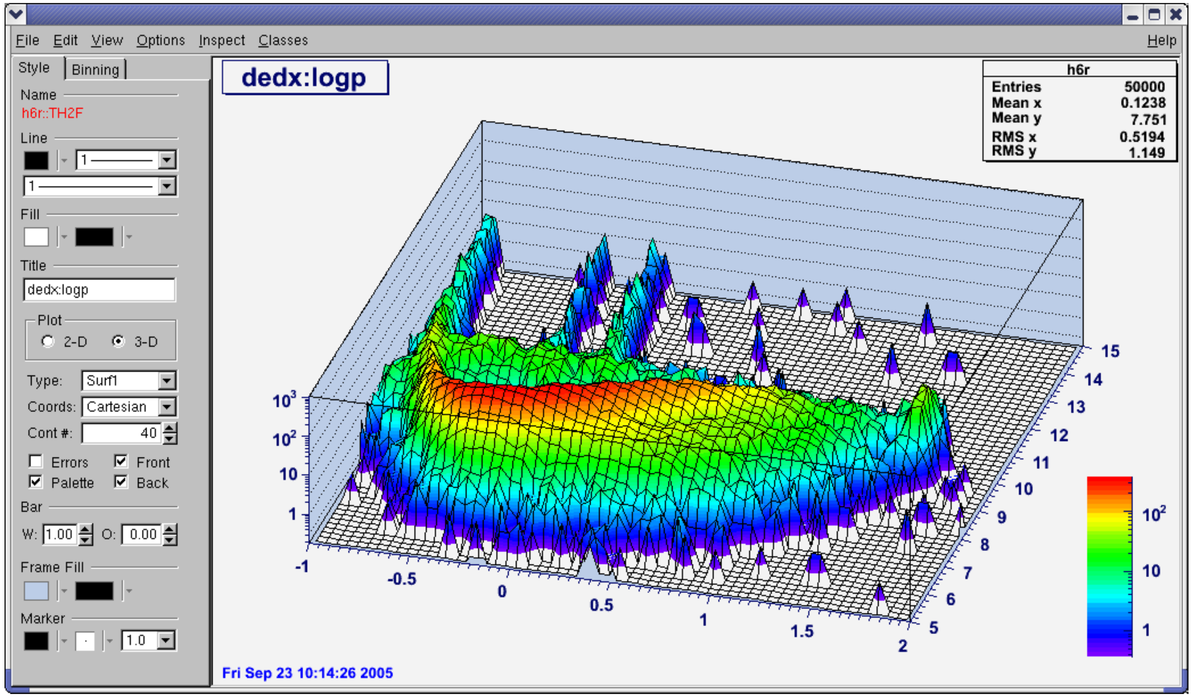
ROOT Graphics

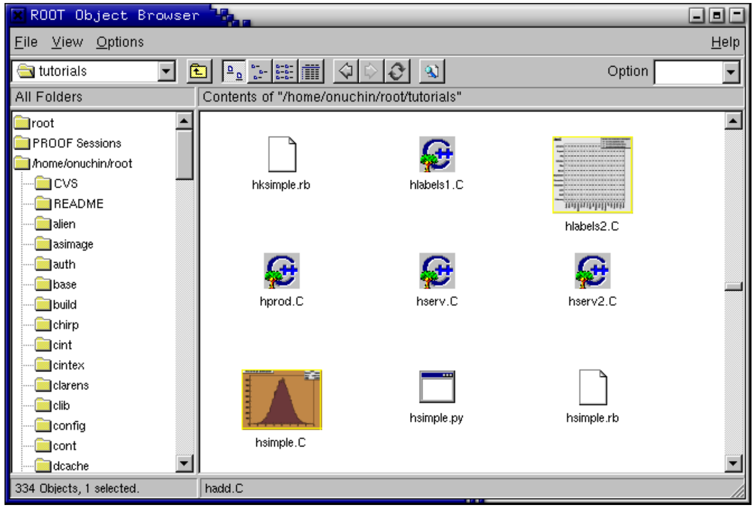


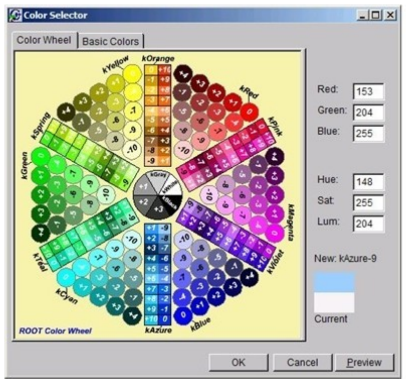
ROOT Graphics

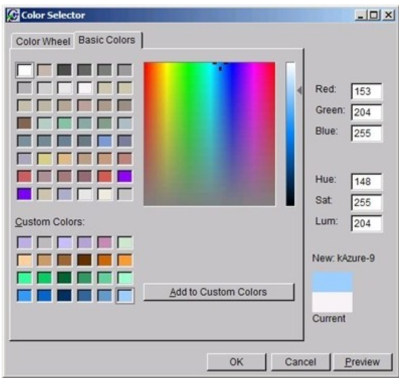


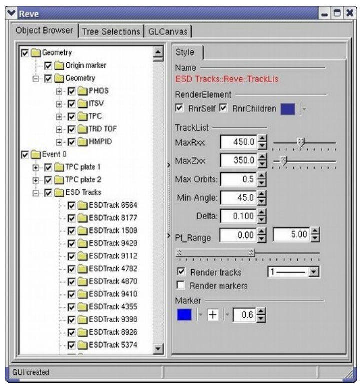
ROOT Graphical Interfaces

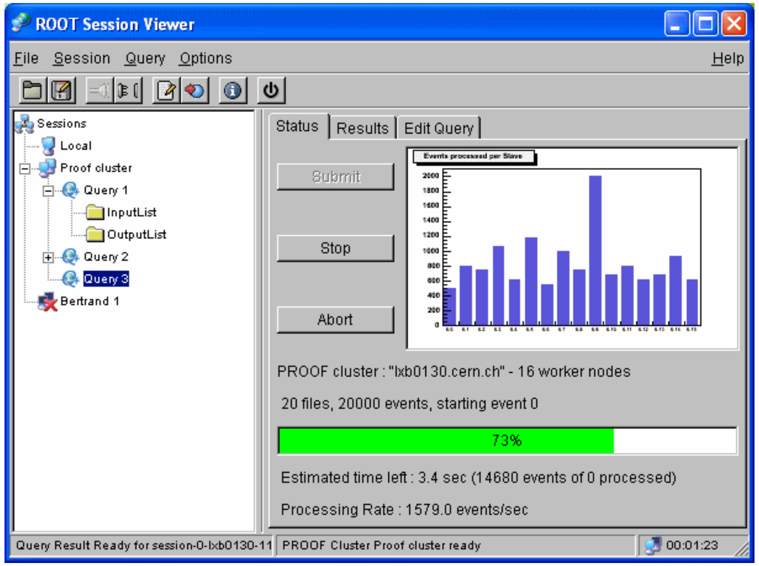




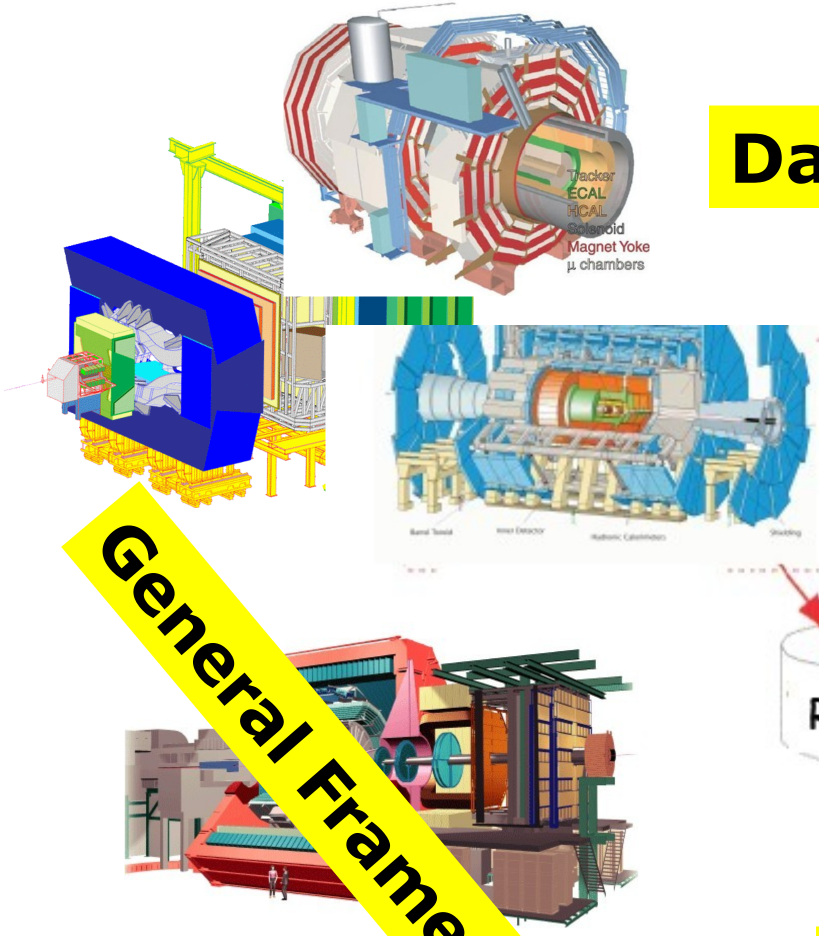






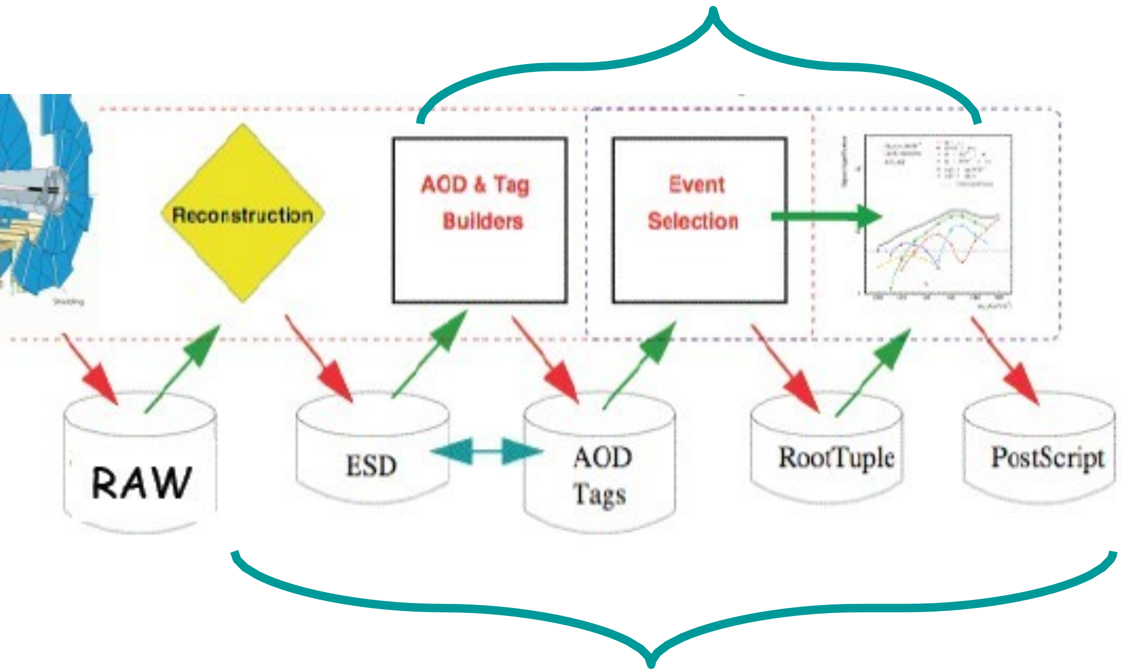


ROOT Application Domains



General Framework

Data Analysis & Visualization



Data Storage: Local, Network

ROOT Download and Installation

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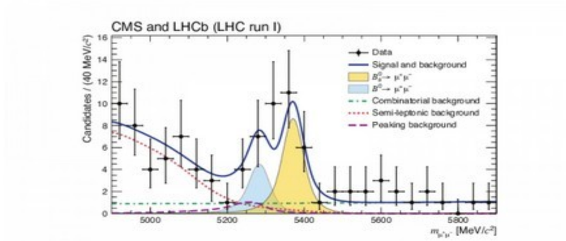
Getting Started Reference Guide Forum Gallery

ROOT is ...

A modular scientific software framework. It provides all the functionalities needed to deal with big data processing, statistical analysis, visualisation and storage. It is mainly written in C++ but integrated with other languages such as Python and R.

Try it in your browser! (Beta)



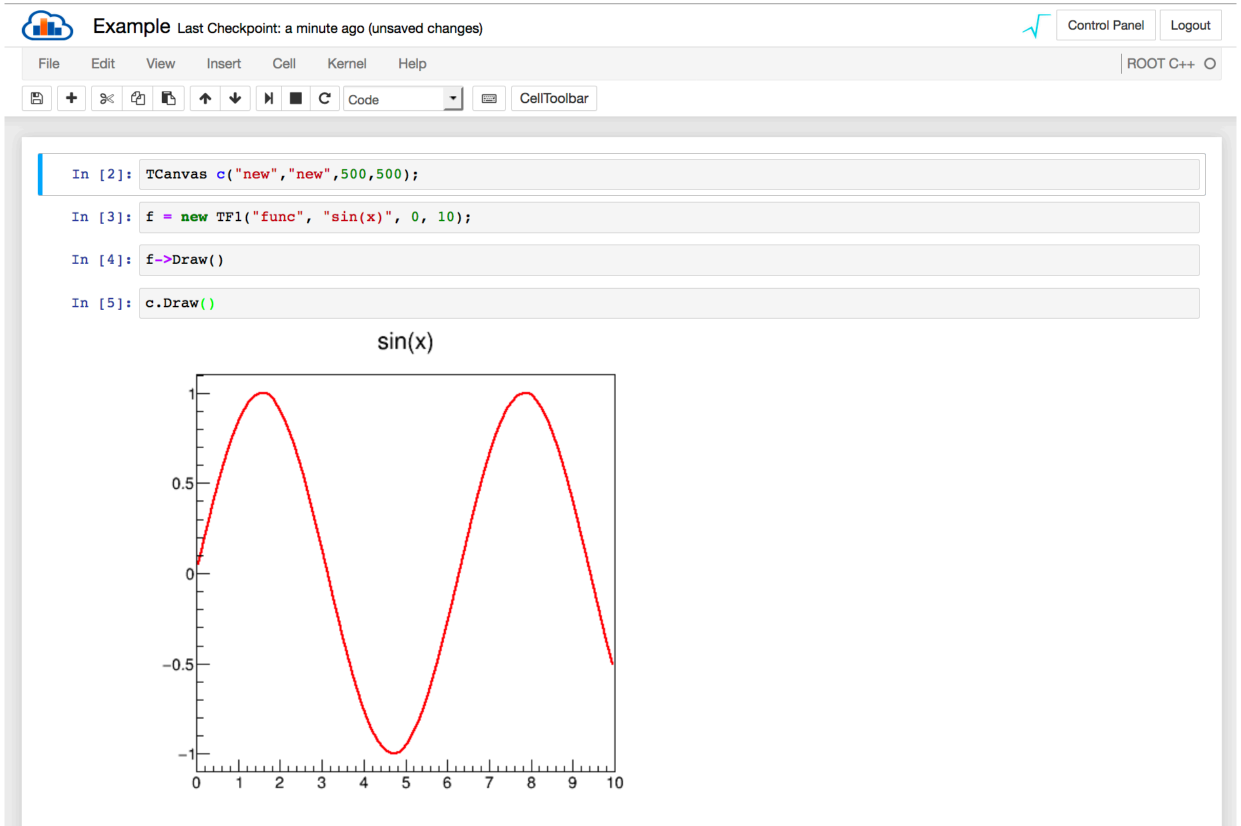
Previous Pause Next

http://root.cern.ch

- *Binaries for common Linux PC flavors, Mac OS, Windows (ROOT5)*
- *Before Installing ROOT, add dependencies, discussed here:*
  - *https://root.cern.ch/build-prerequisites*
- *Linux and MacOS: ROOT6 preferred Windows: ROOT5*
- *Installation guide at:*
  - *https://root.cern.ch/installing-root-source*

If nothing works: http://root.cern.ch/notebooks/rootbinder.html

Interactive ROOT



https://swan.ific.uv.es

- You can log in using username and password provided for the WIFI as :

WIFI Username: ***ABCD***

WIFI Password: ***1234***

https://swan.ific.uv.es/user/jgarcian/notebooks/Example.ipynb

Swan username: ***abcd***

Swan password: ***abcd.1234***

ROOT Resources

Main ROOT page

- http://root.cern.ch

Class Reference Guide

- http://root.cern.ch/root/html

C++ tutorial

- http://www.cplusplus.com/doc/tutorial/
- http://www-root.fnal.gov/root/CPlusPlus/index.html

Hands-on tutorials:

- https://root.cern.ch/courses

ROOT Prompt

***Starting** ROOT*

```
$ root -l
$ root -h
```

```
root[] 2+3                          root[] int i = 42
root[] log(5)                       root[] cout << i << endl;
root[] TMath::Pi()    // try to type also TMath::Pi
```

*ROOT **prompt***

Command history

- *Scan through with arrow keys*
- *Search with CTRL-R (like in bash)*

```
root[] .? //or
root[]  .help
```

Online help

```
root[] new TF1(<TAB>
TF1 TF1()
 TF1 TF1(const char* name, const char* formula, Double_t
   xmin = 0,  Double_t xmax = 1
```

ROOT Prompt (2)

- *Typing multi-line commands*

```
root [ ] for (i=10; i>0; i--) {cout << i <<
  endl;}; cout << "BOOM!!" << endl;
```

```
root [ ] for (i=0; i<3; i++) {
end with '}', '@':abort > printf("%d\n",  i);
end with '}', '@':abort > }
```

- *Aborting wrong input*

```
root [ ] printf("%d\n, i)
end with ';', '@':abort > @
```

Don't panic!
Don't press CTRL-C! Just type @ or .@

ROOT Macros

- *It is quite cumbersome to type the same lines again and again*
- *Create macros for commonly used code Macro*
- *= file that is interpreted by CINT/CLING*

```
int myfirstmacro(int value)
{
  int ret = 42;   ret
  += value;   return
  ret;
}
```

→ **save as myfirstmacro.C**

- *Execute with*

```
root[0] .x myfirstmacro.C(10)
root[0] .L myfirstmacro.C
root[1] myfirstmacro(10)
```

ROOT Macros (2)

- *Combine lines of codes in macros Unnamed*
- *macro*
  - *No parameters*

```
{
  TRandom r;
  for (Int_t i=0; i<10; i++) {  cout
    << r.Rndm() << endl;
  }
  for (Int_t i=0; i<100000; i++)    {
    r.Rndm();
  }
}
```

Data types in ROOT
Int_t (4 Bytes)
Long64_t (8 Bytes)
…
to achieve platform independency

Example : macro1.C

- *Executing macros*

```
root [ ] .x macro1.C
$ root -l macro1.C
$ root -l -b macro1.C (batch mode no graphics)
$ root -l -q macro1.C (quit after execution)
```

Macros Compilation and Libraries

- *"Library": compiled code, shared library CINT/CLING can*
- *call its functions!*
- *Building a library from a macro: ACLiC (Automatic Compiler of Libraries for CINT)*
- *Execute it with a "+"*

```
root [0] .x myfirstmacro.C(42)+
```

or

```
root [0] .L myfirstmacro.C+
root [1] myfirstmacro(42)
```

- *No Makefile needed*
- *CINT knows all functions in the library mymacro_C.so/.dll*

Compiled vs Interpreted

Why compile?

- *Faster execution, CINT/CLING has some limitations…*

Why interpret?

- *Faster Edit → Run → Check result → Edit cycles ("rapid prototyping"). Scripting is sometimes just easier*

So when should I start compiling?

- *For simple things: start with macros*
- *Rule of thumb*
  - *Is it a lot of code or running slow?* ***Compile it!***
  - *Does it behave weird?* ***Compile it!***
  - *Is there an error that you do not find.* ***Compile it!***

Objects

A (mathematical) function TF1 is an object: has data members/methods

Constructor:
makes an instance of the object

```
root [0] TF1 f("myFunction", "sin(x)/x", 0, 10)
root [1] f
(class TF1)40879392
```

Name — Formula — Range (min/max)

Methods:
ask for/modify properties of the object

```
root [3] cout << f.GetName() << endl
myFunction
root [4]
root [4] f.SetName("myFunctionWithNewName")
root [5]
root [5] cout << f.GetName() << endl
myFunctionWithNewName
```

Data members:
properties of the object generally inaccessible to us can be modified with setters/getters

From the **TF1.h** class

```
Double_t    fXmin;        //Lower bounds for the range
Double_t    fXmax;        //Upper bounds for the range
```

Functions

The class TF1 allows to draw functions

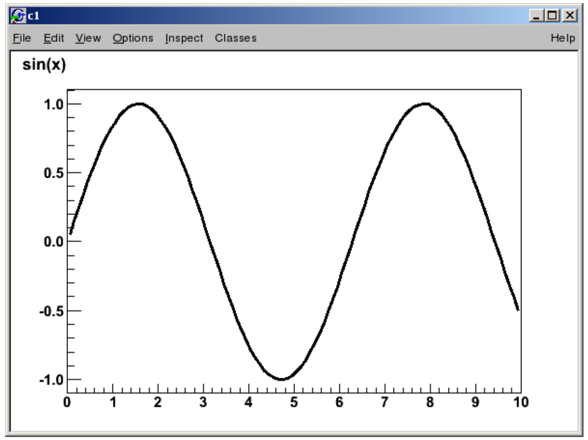
```
root [ ] f = new TF1("func", "sin(x)", 0, 10)
```

"func" is a (unique) name

"sin(x)" is the formula

0, 10 is the x-range for the function

```
root [ ] f->Draw()
```



Canvas

The style of the function can be changed on the command line or with the context menu (right click)

```
root [ ] f->SetLineColor(kRed)
```

The class TF2(3) is for 2(3)-dimensional functions

Pointers vs Value Types

- *A value type contains an instance of an object*
- *A pointer points to the instance of an object*
- *Create a pointer*

```
root [ ] TF1* f1 = new TF1("func", "sin(x)", 0, 10)
```

- *Create a value type*

```
root [ ] TF1 f2("func", "cos(x)", 0, 10)
```

- *One can point to the other*

```
TF1 f1b(*f1)        // dereference and create a copy
TF1* f2b = &f2      // point to the same object
```

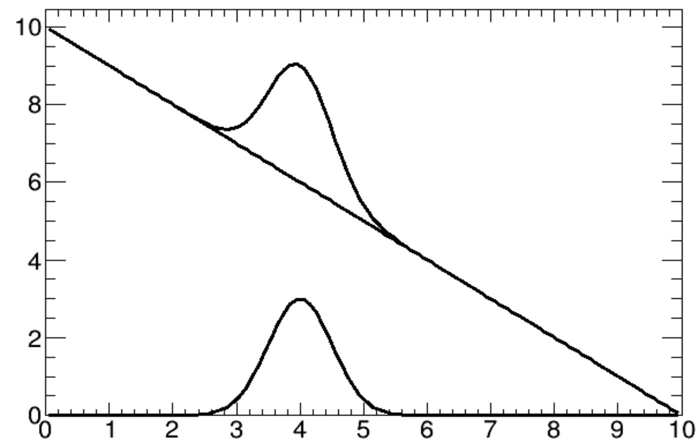
Naming Conventions

How does ROOT call its classes and functions?

- Class names start with capital T, e.g. **TF1**
- Class data members start with f, e.g. **fXmin**
- Names of non-class data types end with _t: e.g. **Int_t**
- Class methods start with _t: e.g. **GetName()**
- Global variable names start with _t: e.g. **gPad**
- Constant (or enumerator) names start with k: e.g. **kTrue**
- Words in names are capitalized: e.g. **GetLineColor()**
- Two subsequent capital letters are avoided: e.g. **GetXaxis()**

Functions

```
root [ ] TF1 *f1 = new TF1("f1","gaus(x)",0,10)
root [ ] TF1   *f2 = new TF1("f2","10.-x",0,10)
root [ ] f2->SetParameter(0,1)
root [ ] f2->Draw()
root [ ] f1->SetParameter(0,2)
root [ ] f1->SetParameter(1,4)
root [ ] f1->SetParameter(2,2.5)
root [ ] f1->Draw()
root [ ] TF1 *f3 = new
TF1("f3","f1+f2",0,10)
root [ ] f3->Draw()
root [ ] f3->SetParameter(0,3)
root [ ] f3->SetParameter(2,0.5)
root [ ] f3->Draw()
root [ ] f2->Draw("same")
root [ ] f1->SetParameter(0,3)
root [ ] f1->SetParameter(2,0.5)
root [ ] f1->Draw("same")
```



Now play a bit with the function class and graphical options.
Can you change the background shape from a linear function to an exponential function?
How to save the graphical window (it is called Canvas)?
code in function.C

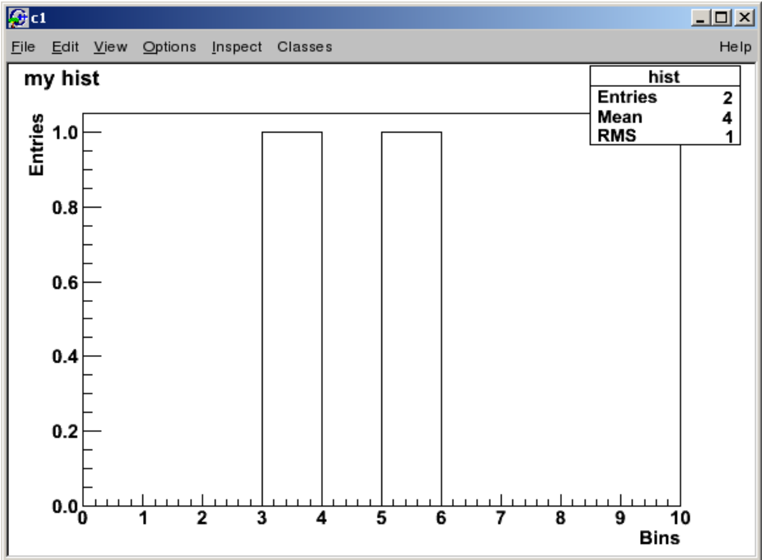
Histograms

Contain binned data – probably the most important class in ROOT for the physicist

***Create** a TH1F (= one dimensional, float precision)*

```
root[] h = new TH1F("hist", "my hist;Bins;Entries", 10, 0, 10)
```

- ***"hist"** is a (unique) name*
- ***"my hist;Bins;Entries"** are the title and the x and y labels*
- ***10** is the number of bins*
- ***0, 10** are the limits on the x axis. Thus the first bin is from 0 to 1, the second from 1 to 2, etc.*



***Fill** the histogram*

```
root[] h->Fill(3.5)
root[] h->Fill(5.5)
```

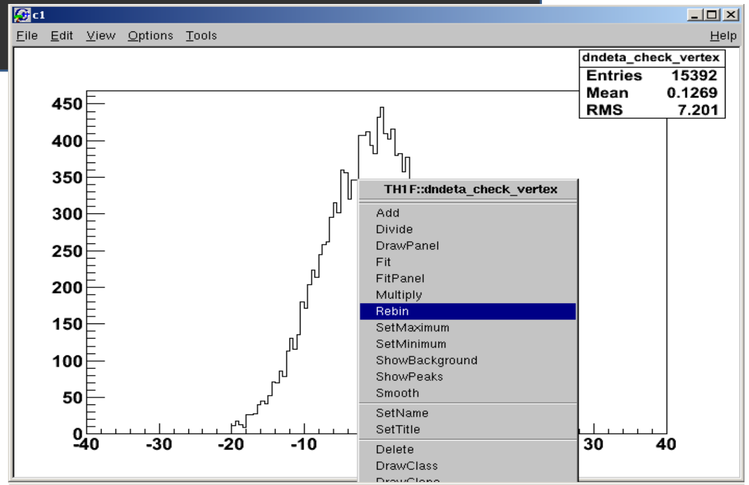
***Draw** the histogram*

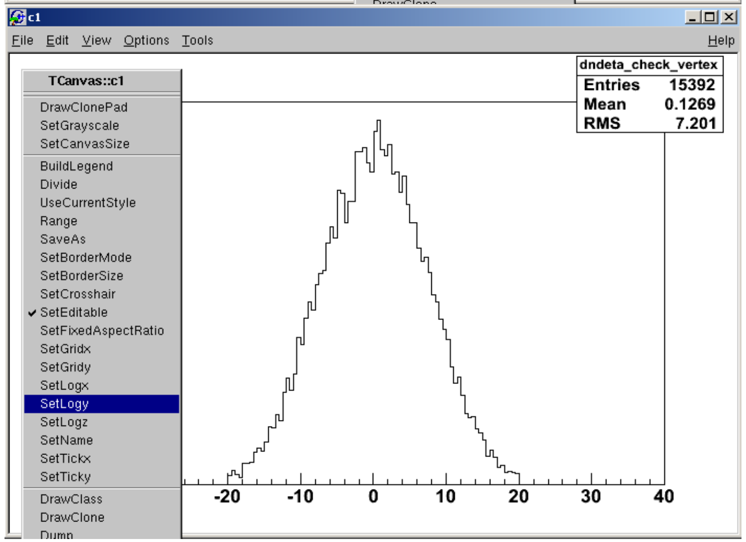
```
root[] h->Draw()
```

A bin includes the lower limit, but excludes the upper limit

Histograms (2)

```
root[] TH1F h("h","h",80,-40,40)
root[] TRandom r;
root[] for (i=0;i<15000;i++) { h.Fill(r.Gaus(0,7));}
root[] h.Draw()
```





Rebinning

```
root[] h.Rebin(2)
```

Change ranges/canvas

- *with the mouse, very easy!*
- *with the context menu*
- *command line*

```
root[] h.GetXaxis()->
   SetRangeUser(2, 5)
```

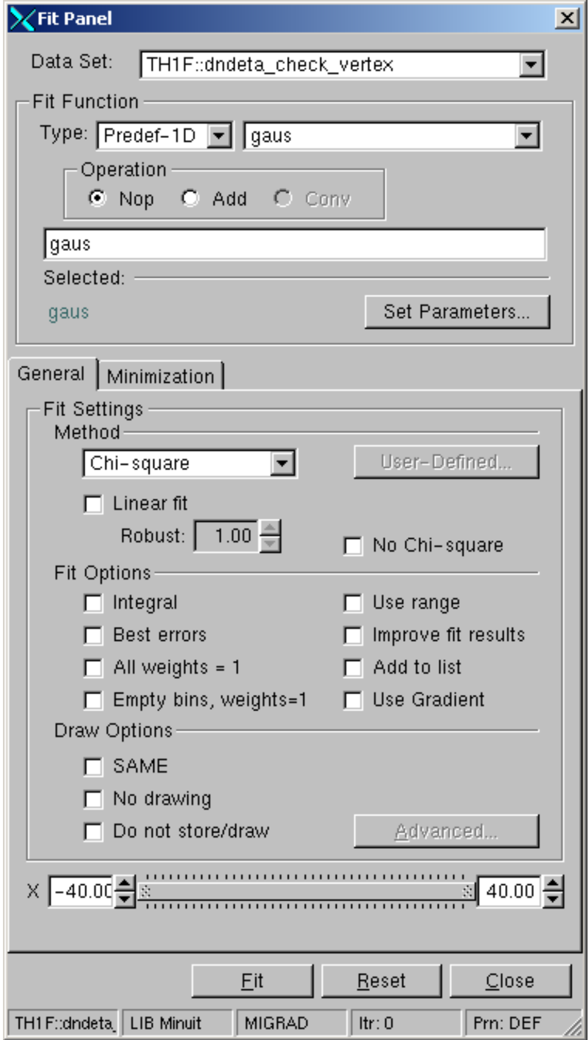
Log-view

- *right-click in the white area at the side of the canvas and select SetLogx (SetLogy)*
- *command line*

```
root[] gPad->SetLogy()
```

Interactive

- *Right click on the histogram and choose "fit panel"*
- *Select function and click fit*
- *Fit parameters*
  - *are printed in command line*
  - *in the canvas: options - fit parameters*



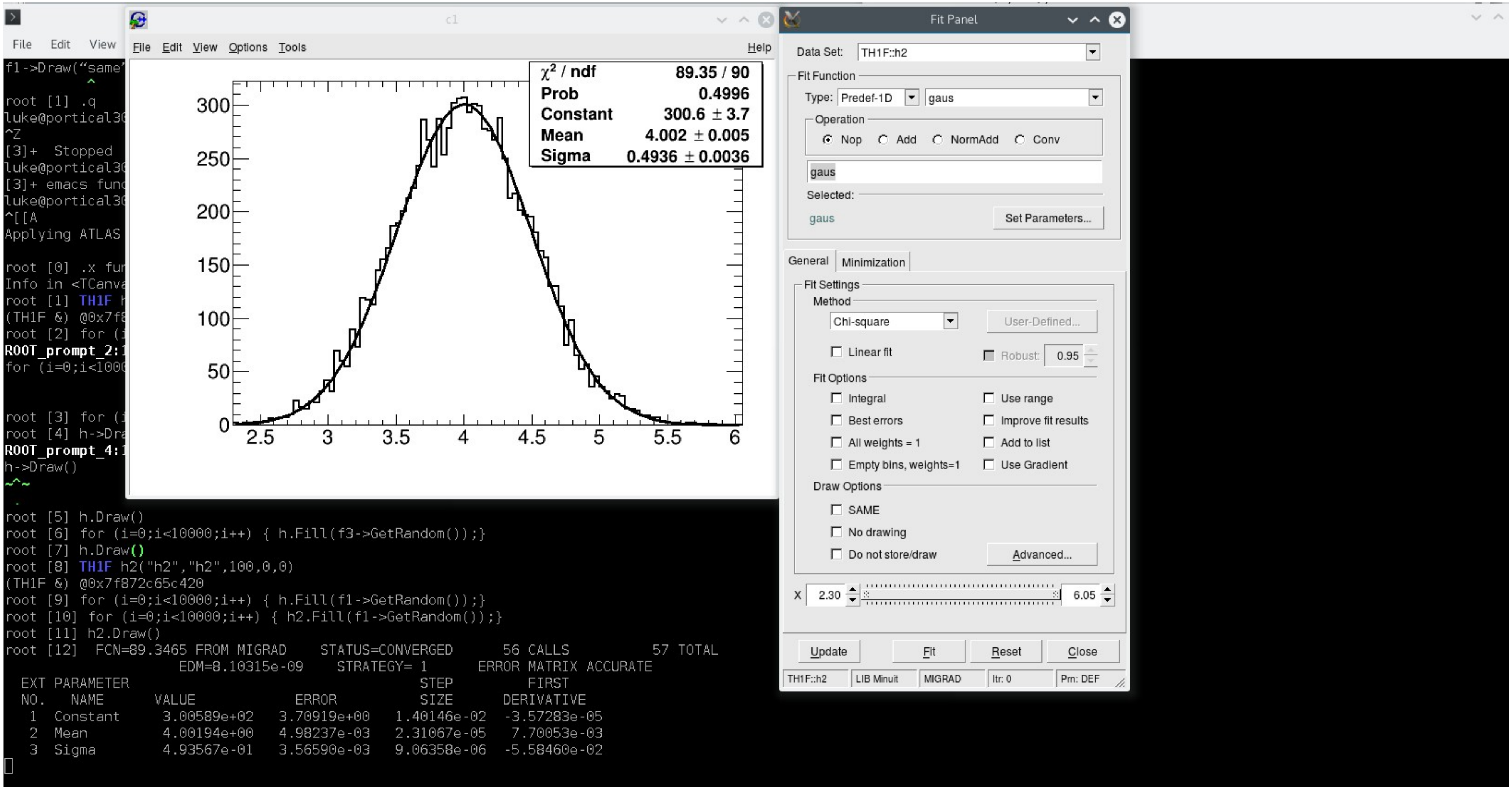
Command line

```
root [ ] h.Fit("gaus")
```

- *Other predefined functions*
  polN (N = 0..9), expo, landau

Try to fit the histogram with different functions.

Fitting Histograms (2)



Fitting Histograms (3)

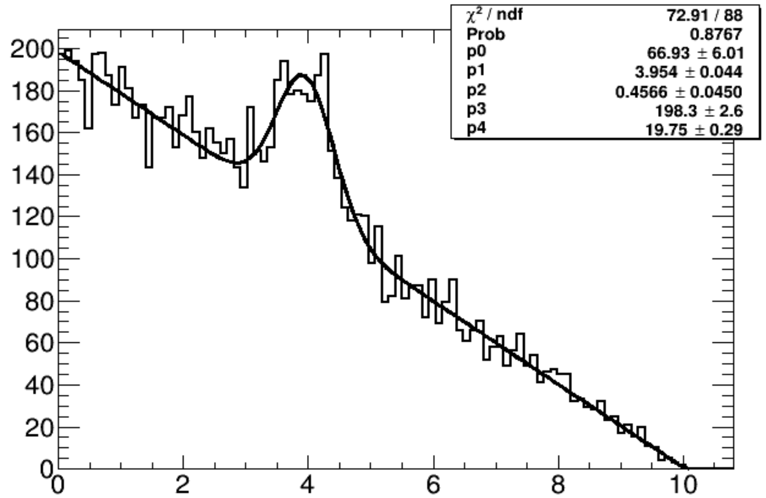
Now edit function.C

```
root [ ] TH1F  h("h","h",100,0,0); //auto range
root [ ] for (i=0;i<10000;i++) { h.Fill(f3->GetRandom());}
//create random  numbers according to function
root [ ] h.Draw()
```

Try to fit the the histogram:

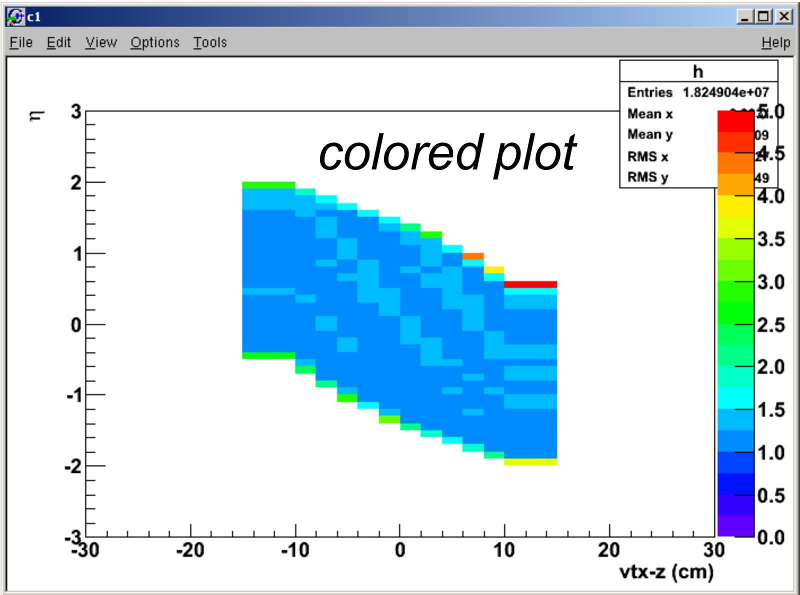
```
root [ ] TF1* f4 = new TF1(“f4”,”.....”,0,10)
```

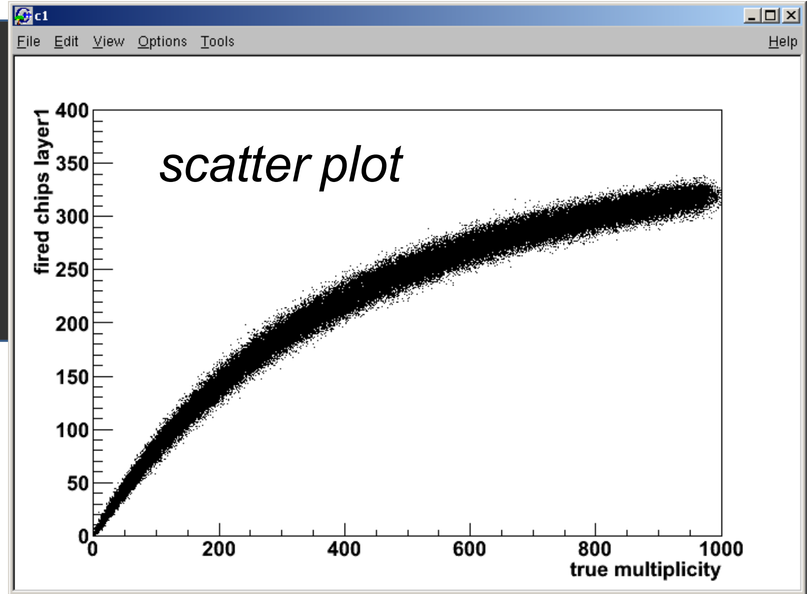
Tip: *A Gaussian function can be written as:*
*[0]*TMath::Exp(-0.5* ((x-[1])/[2])*((x-[1])/[2]))*

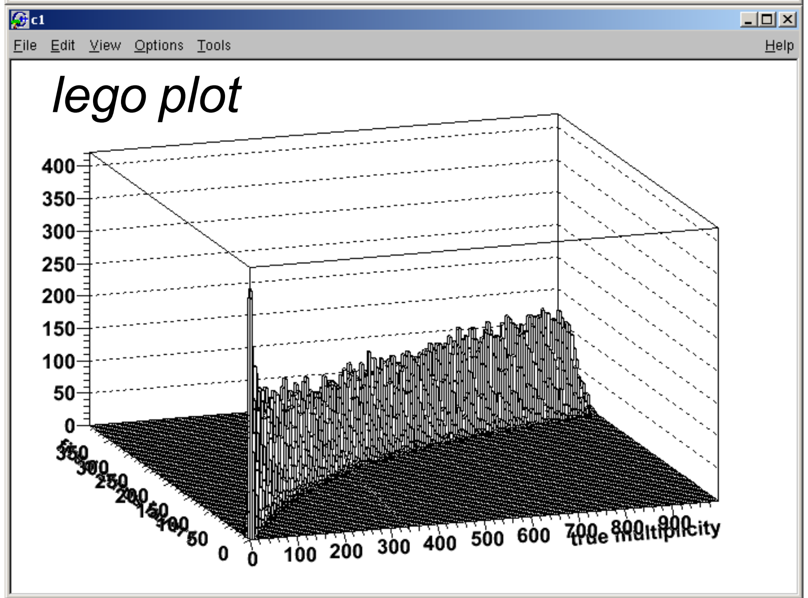


2D Histograms

```
root [ ] h->Draw()
root [ ] h->Draw("LEGO")
root [ ] h2->Draw("COLZ")
```







NB: h and h2 are in file hist2.root

get nicer colors in COLZ plots by gStyle->SetPalette(1, 0)

Files

The class TFile allows to store any ROOT object on the disk
Create a histogram like before with

```
TH1F* h = new TH1F("h", "my hist;…", 10, 0, 10)
TH1F hist("hist", "test", 100, -3, 3);
hist.FillRandom("gaus", 1000);
```

"hist" will be the name in the file

```
// Open a file for writing
root [ ] file = TFile::Open("file.root", "RECREATE")
// Write an object into the file
root [ ] h->Write()
root [ ] hist->Write()
// Close the file
root [ ] file->Close()
```

NEW
READ
RECREATE
UPDATE
….

Files (2)

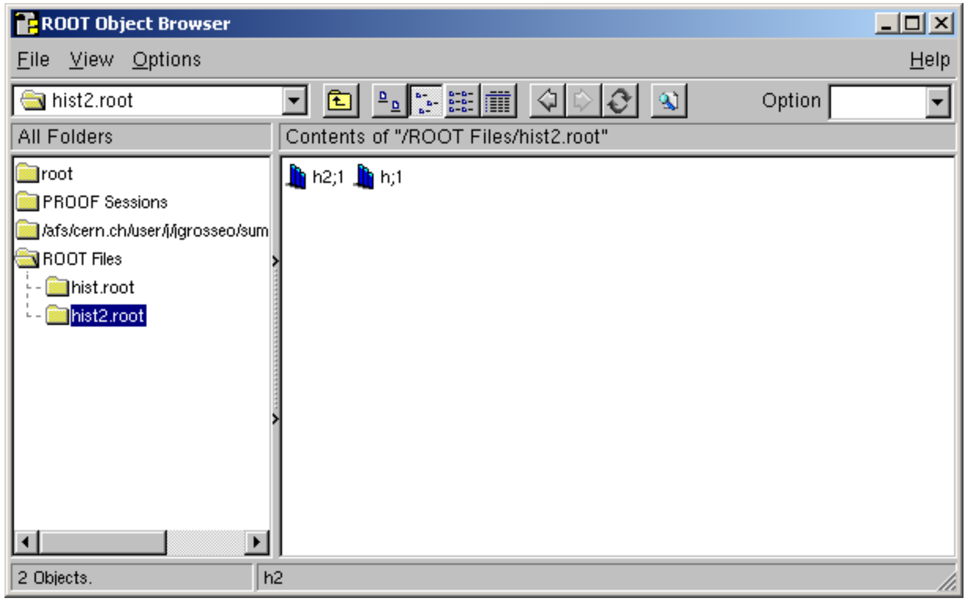
```
// Open the file for reading
root [ ] file = TFile::Open("file.root")
// Read the object from the file
root [ ] hist->Draw()
// (only works on the command line!). In a
macro read the object with
TH1F* h = 0;
file->GetObject("hist", h);
// What else is in the file?
root [ ] .ls
// Open a file when starting root
$ root file.root
// Access it with the _file0 or gFile pointer
```

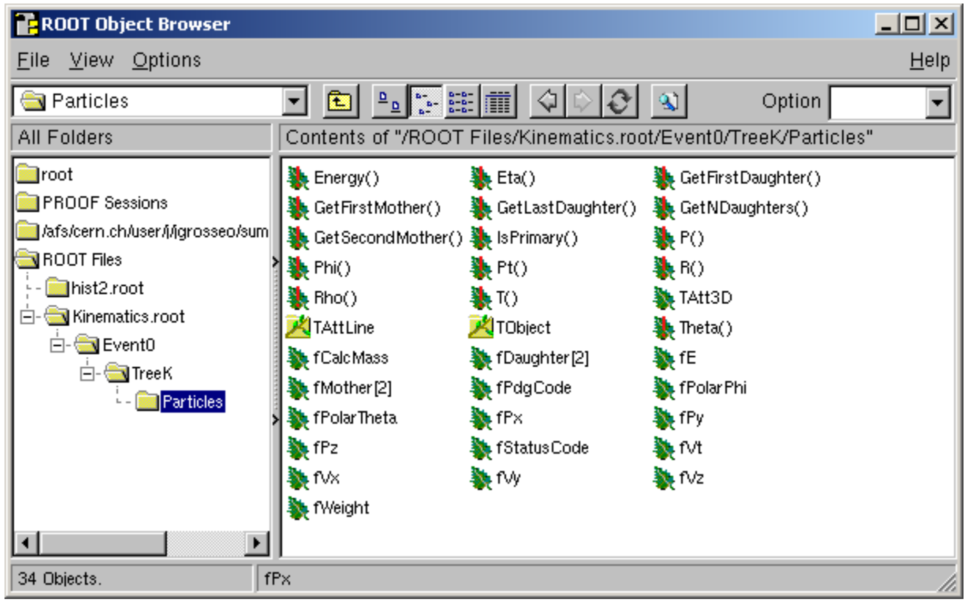
Object ownership After reading an object from a file don't close it! Otherwise your object is not in memory anymore

TBrowser

- *The TBrowser can be used*
  - *to open files*
  - *navigate in them*
  - *to look at TTrees*
- *Starting a TBrowser*

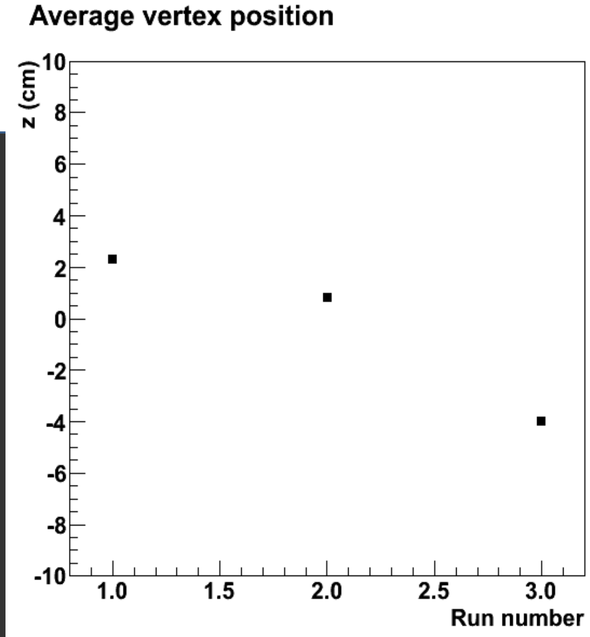
  `root [ ] new TBrowser`
- *Open a file*
- *Navigate through the file*
- *Draw a histogram*
- *Change the standard style*
  - *Drop down menu in the top right corner*
- *Access a tree*
- *Plot a member*





Graphs

- *A graph is a data container filled with distinct points*
- *TGraph: x/y graph without error bars*
- *TGraphErrors: x/y graph with error bars TGraphAsymmErrors:*
- *x/y graph with asymmetric error bars*




```
graph = new TGraph;
graph->SetPoint(graph->GetN(), 1, 2.3);
graph->SetPoint(graph->GetN(), 2, 0.8);
graph->SetPoint(graph->GetN(), 3, -4);
graph->Draw("AP");
graph->SetMarkerStyle(21);
graph->GetYaxis()->SetRangeUser(-10, 10);
graph->GetXaxis()->SetTitle("Run number");
graph->GetYaxis()->SetTitle("z (cm)");
graph->SetTitle("Average vertex position");
```

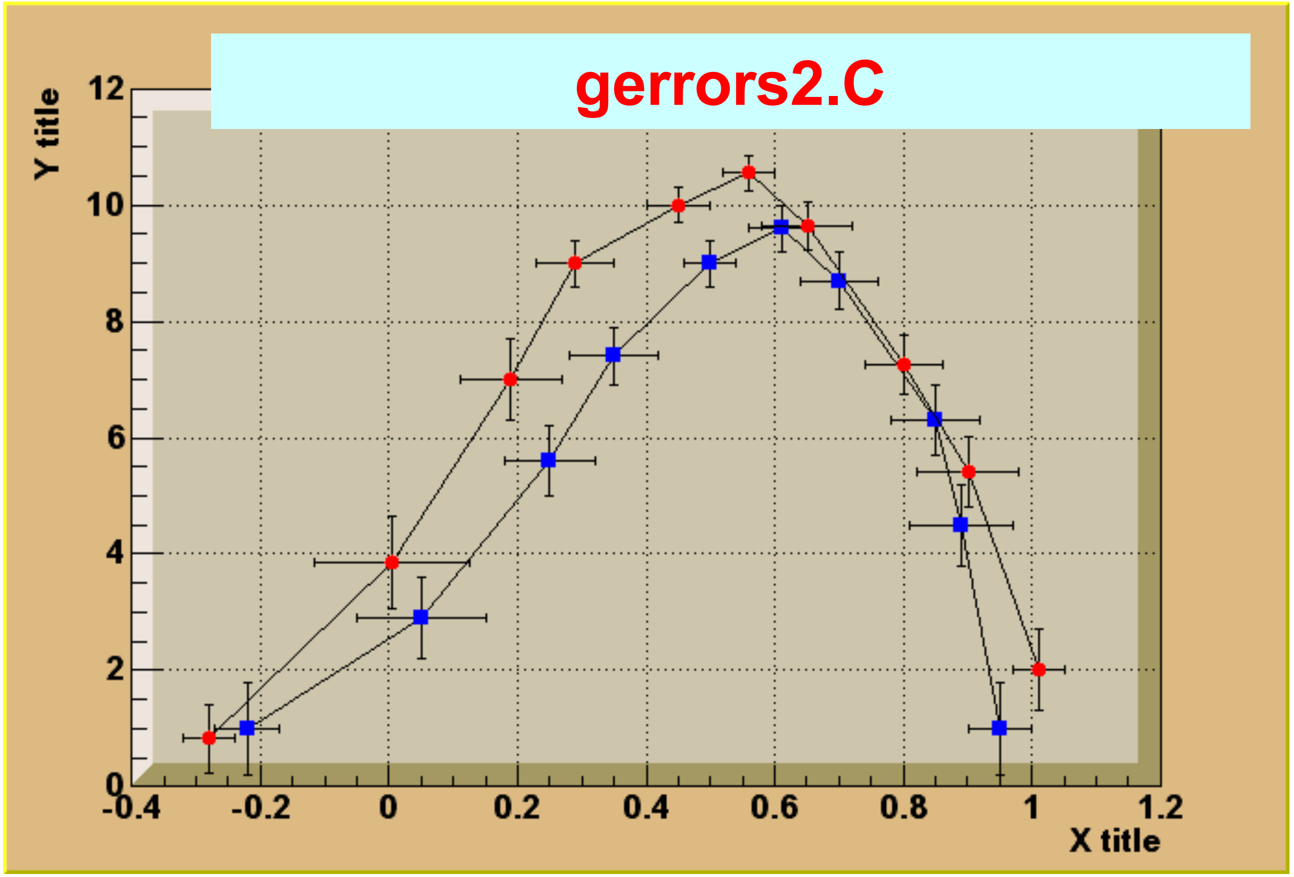
Graphs (2)

TGraphErrors(n,x,y,ex,ey)

TGraph(n,x,y)

TCutG(n,x,y)

TMultiGraph

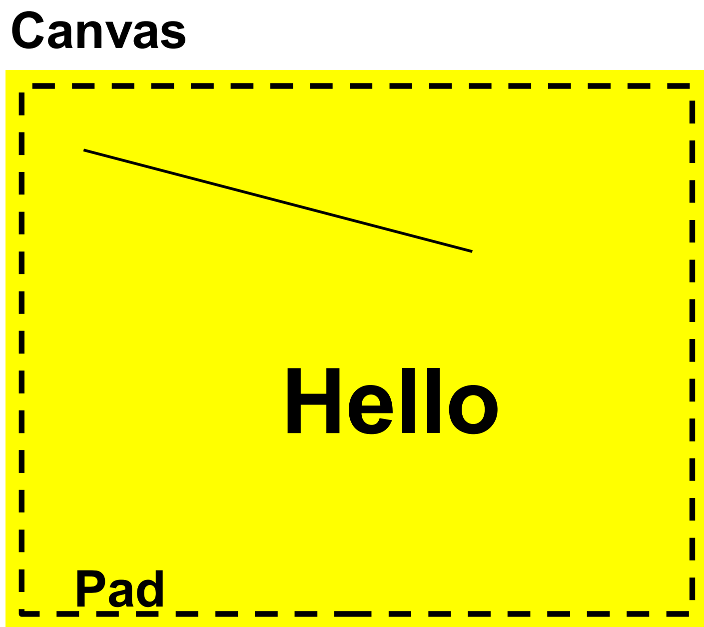


TGraphAsymmErrors(n,x,y,exl,exh,eyl,eyh)

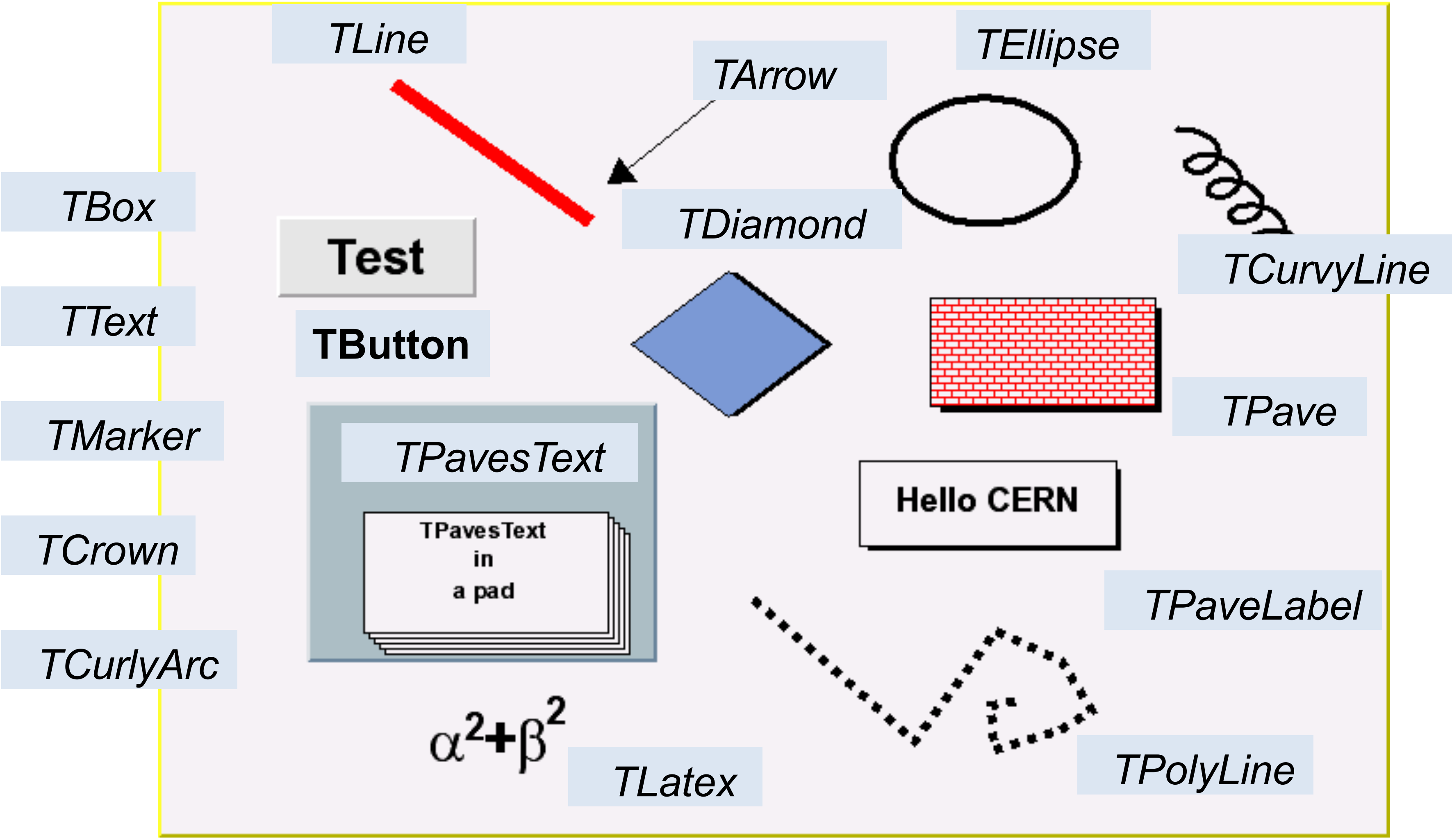
Graphic Objects

- *You can draw with the command line*
- *The Draw function adds the object to the list of primitives of the current pad*
- *If no pad exists, a pad is automatically created*
- *A pad is embedded in a canvas*
- *You create one manually with new TCanvas*
  - *A canvas has one pad by default*
  - *You can add more*

```
root [ ] TLine line(.1,.9,.6,.6)
root [ ] line.Draw()
root [ ] Ttext text(.5,.2,"Hello")
root [ ] text.Draw()
```

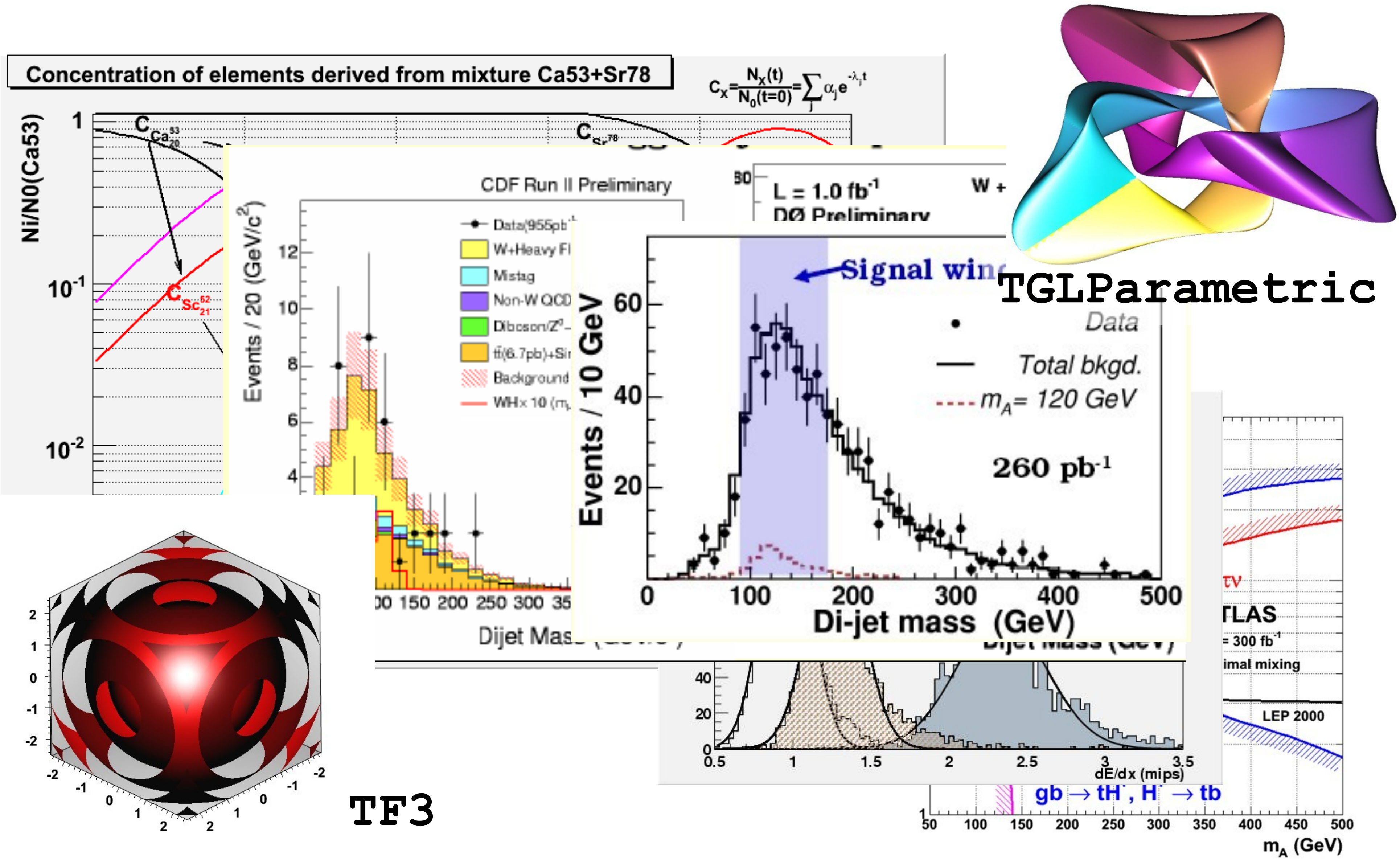


More Graphic Objects



Can be accessed with the toolbar
View > Toolbar (in any canvas)

Graphic Examples



What is a ROOT Tree?

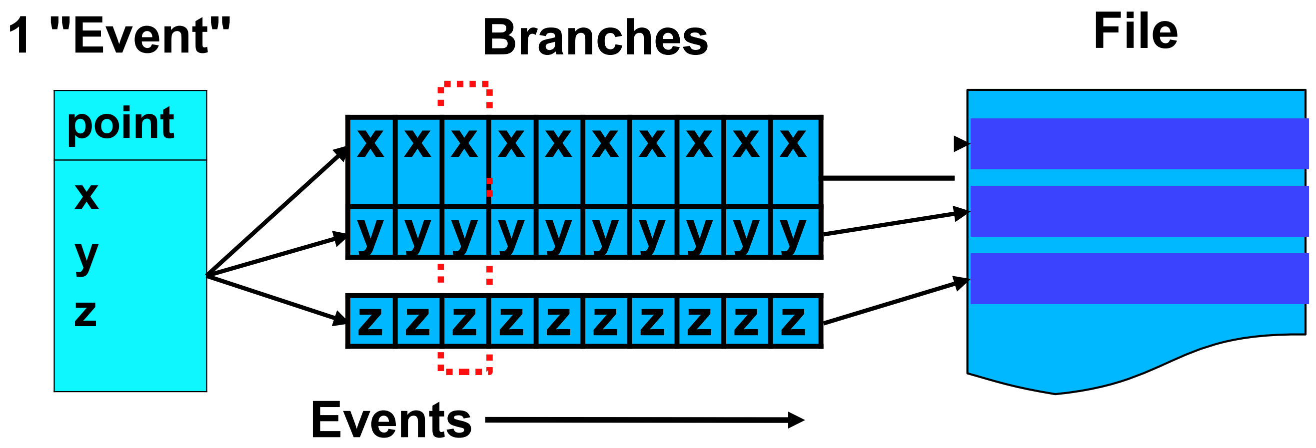
- *Trees have been designed to support very large collections of objects. The overhead in memory is in general less than 4 bytes per entry.*
- *Trees allow direct and random access to any entry (sequential access is the most efficient)*

The class TTree is the main container for data storage

It can store any class and basic types (e.g. Float_t)

When reading a tree, certain branches can be switched off

- *speed up of analysis when not all data is needed*



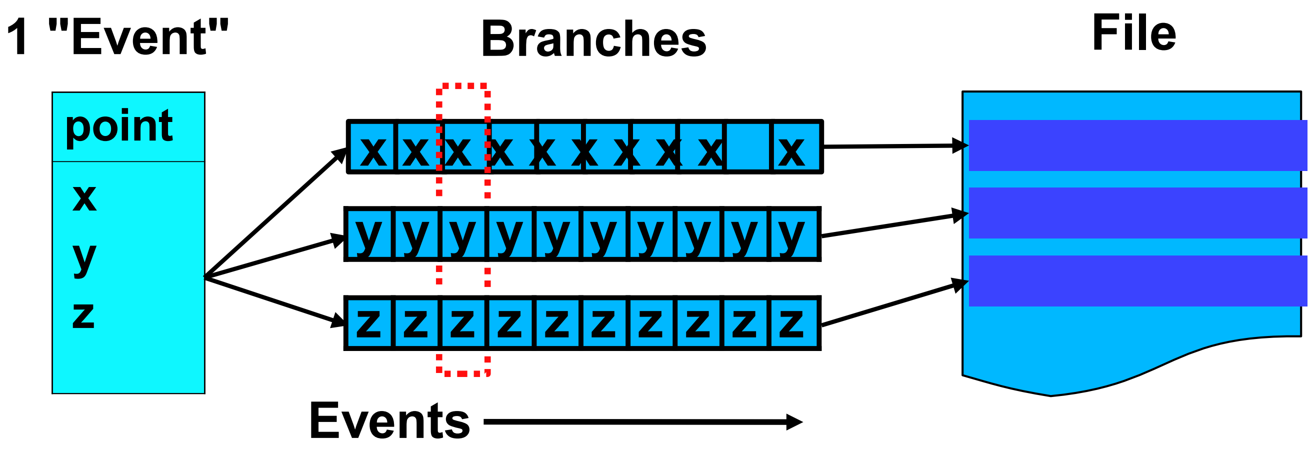
Tree

Trees are structured into branches and leaves. One can read a subset of all branches

High level functions like TTree::Draw loop on all entries with selection expressions

Trees can be browsed via TBrowser Trees can

be analyzed via TTreeViewer



Tree Writing

- *You want to store objects in a tree which is written into a file*
- *Initialization*

```
root[] TFile* f = TFile::Open("events.root","RECREATE");
root[] TTree* t = new TTree("Events","Event Tree");
root[] Int_t var1;
root[] Float_t var2;
root[] Float_t var3;
root[] t->Branch("var1", &var1, “var1/I”);
root[] t->Branch("var2", &var2, “var2/F”);
root[] t->Branch("var3",     &var3, “var3/F”);
```

Tree Writing (2)

```
root [ ] var1=5; var2=3.1; var3=10.;
// Now Fill the Tree. Fill copies content into Tree entry
root [ ] t->Fill();
// Again
root [ ] var1=1; var2=7; var3=4.5;
root [ ] t->Fill();

// Inspect the Tree
root [ ] t->Print();
// Show entry's content
root [ ] t->Show(1);
// Write into File
root [ ] t->Write();
// Close File
root [ ] f->Close();
```

Code is in: simpletree.C

Tree Reading

- *Open the file, retrieve the tree and connect the branch with a pointer to TMyEvent*

```
TFile *f = TFile::Open("events.root");
TTree *tree = (TTree*)f->Get("Events");
Float_t var2;
tree->SetBranchAddress("var2", &var2);
```

- *Read entries from the tree and use the content of the class*

```
Int_t nentries = tree->GetEntries();
for (Int_t i=0;i<nentries;i++) {
 tree->GetEntry(i);
 cout << var2 << endl;
}
```

A quick way to browse through a tree is to use a TBrowser or TTreeViewer

Code is in: readtree.C

More on Trees

Accessing a more complex objects from non-standard classes

- *Members are accessible even without the proper class library*
- *Might not work in all frameworks*

Example: eventdata.root (containing kinematics from ALICE)

```
$ root eventdata.root
root [ ] tree->Scan();
root [ ] tree->Scan("*");
root [ ] tree->Scan("fParticles.fPosX:fParticles.fPosY:fParticles.fPosZ");
root [ ] tree->Scan("fParticles.fPosX:fParticles.fPosY:fParticles.fPosZ",
    "fParticles.fPosX<0")
```

More on Trees (2)

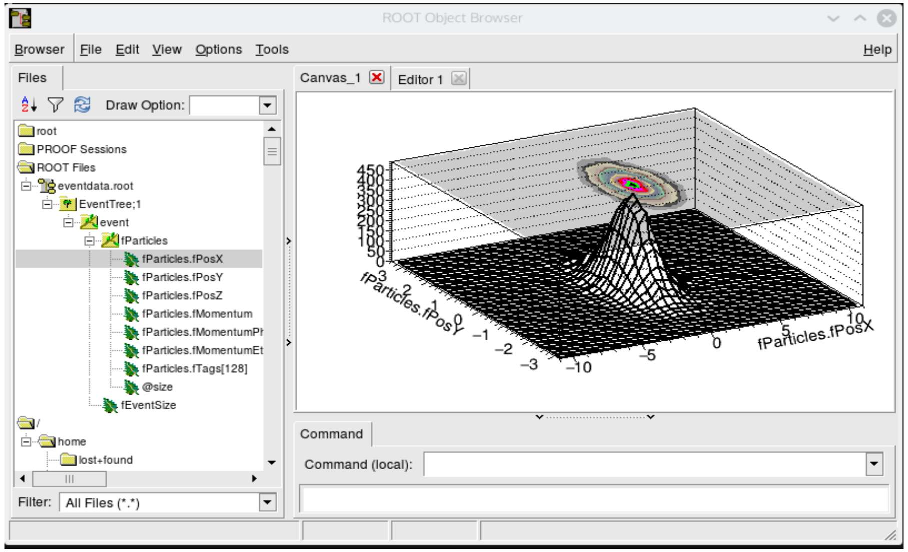
Accessing a more complex objects from non-standard classes

- *Members are accessible even without the proper class library*
- *Might not work in all frameworks*

Example: eventdata.root (containing kinematics from ALICE)

```
$ root eventdata.root
root [ ] tree->Draw("fParticles.fPosX")
root [ ] tree->Draw("fParticles.fPosY:fParticles.fPosX")
root [ ] tree->Draw("fParticles.fPoxY", "fParticles.fPoxX< 0")
```

- *Perform more complex selections*
- *Plot 1D, 2D histograms with different styles*
- *Perform fits of some of these distributions*

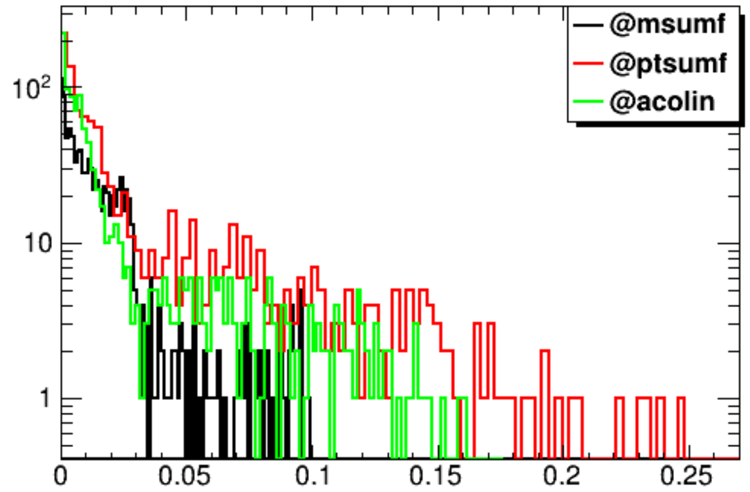


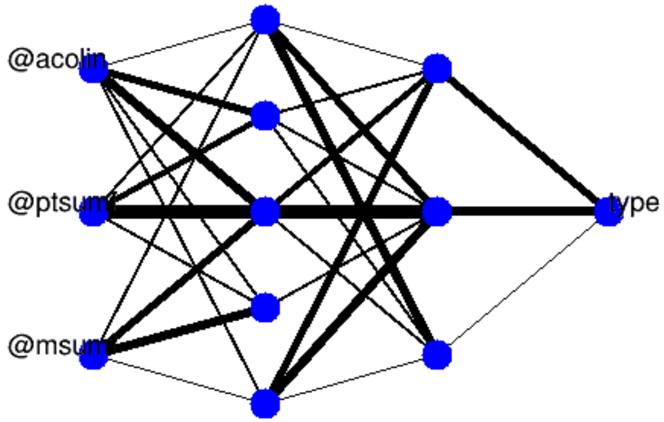
Machine Learning

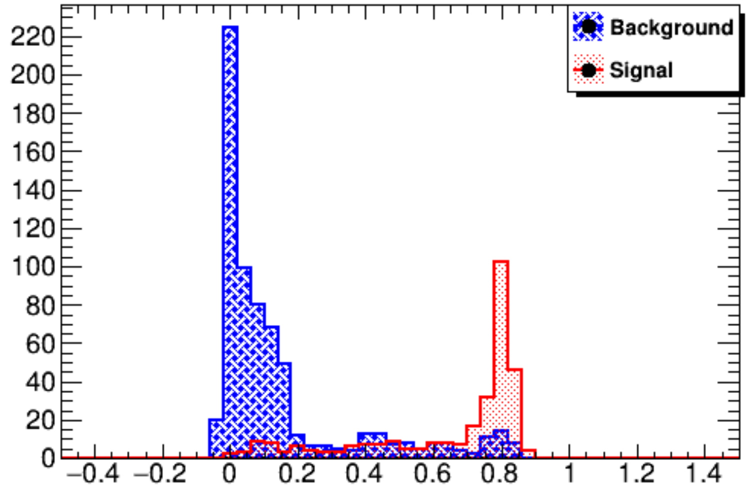
- *Example of advanced statistical analysis:*
  - *Read from a tree the event variables for:*
    - *"signal" process, e.g. a simulation of a new phenomena you are looking for.*
    - *simulation of a "background process you want to separate the signal from.*
  - *Build a Neural Network with these variables, whose separation of the signal to background is much better than the each of the input variables.*
  - *Launch the macro: mlpHiggs.C*
  - *Check the contents of the macro and of the mlpHiggs.root file:*

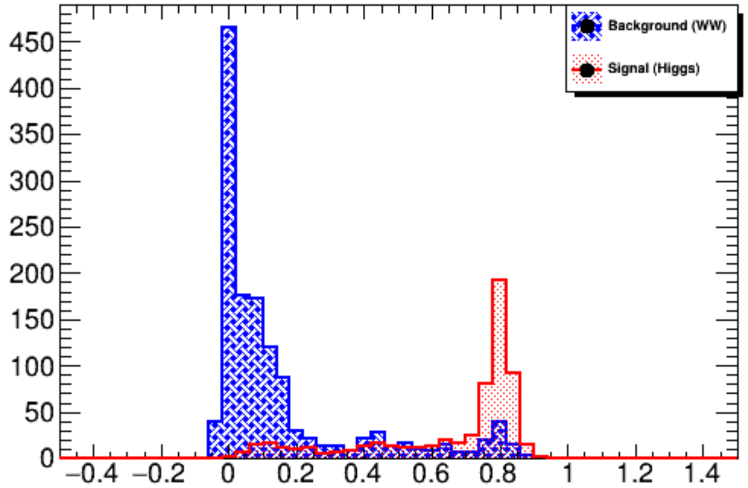
TFile::Open("http://root.cern.ch/files/mlpHiggs.root")

Machine Learning (2)





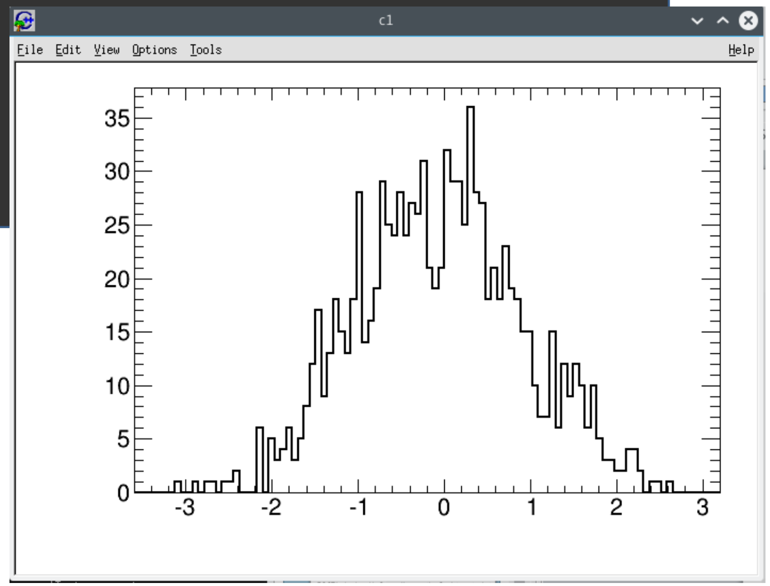




PyRoot

ROOT is developed in C++ and has a native C++ interpretar, but it is interfaced also to other languages, such as python.

```
$ python
In [1]: import ROOT
In [2]: h = ROOT.TH1F("h", "h", 100, 0, 0)
In [3]: h.GetName()
Out[3]: 'h'
In [4]: r= ROOT.TRandom()
In [5]: for i in xrange(0,1000):
h.Fill(r.Gaus())
In [6]: h.Draw()
```



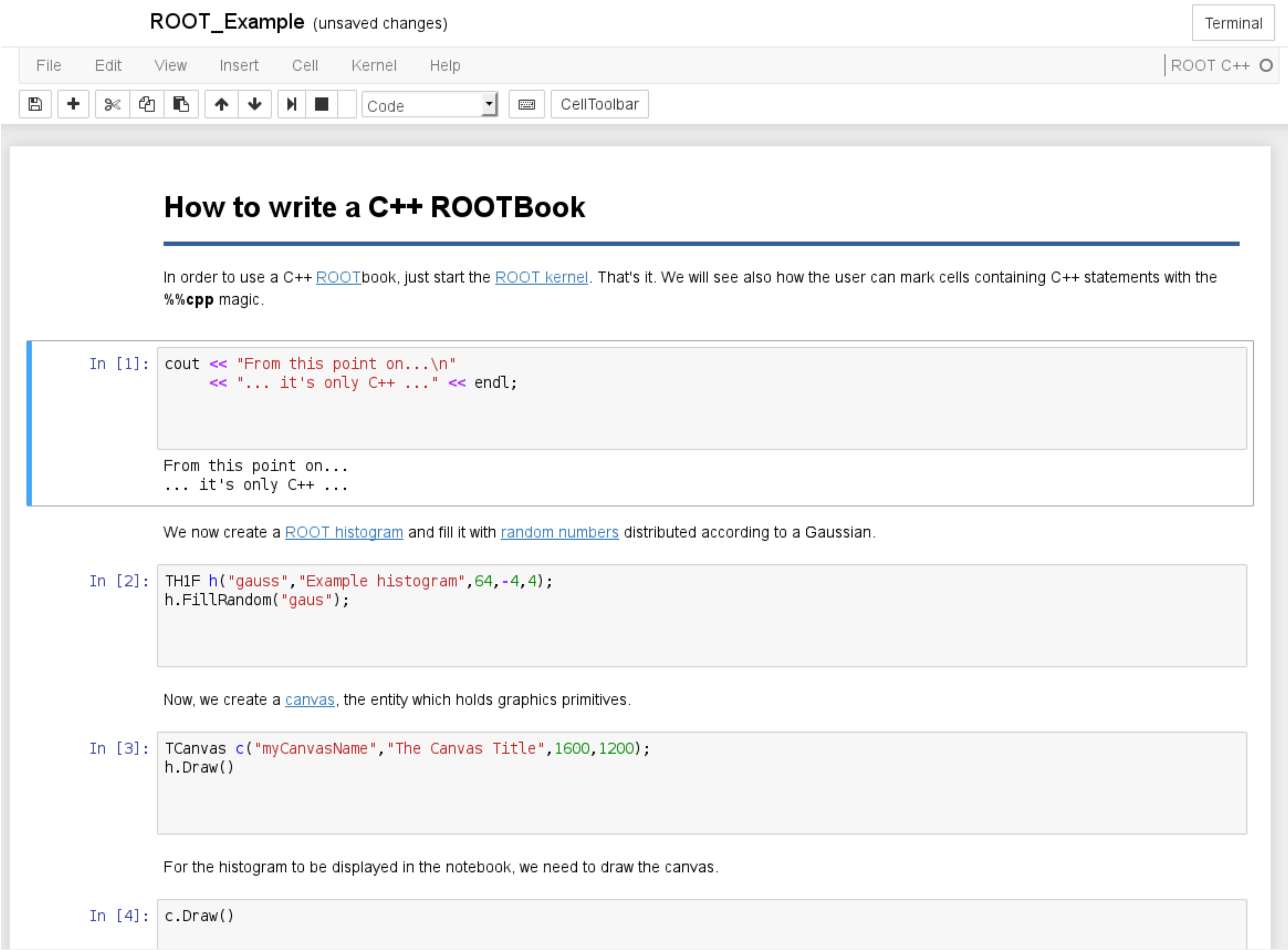
Now you can redo all the tutorial in python if you wish!

python™

RootBook

Interactive ROOT in your Browser!

https://app.mybinder.org:80/3000949792/notebooks/index.ipynb



ROOT_Example (unsaved changes)

Terminal

File Edit View Insert Cell Kernel Help

ROOT C++

Code

CellToolbar

How to write a C++ ROOTBook

In order to use a C++ ROOTbook, just start the ROOT kernel. That's it. We will see also how the user can mark cells containing C++ statements with the **%%cpp** magic.

In [1]:
```
cout << "From this point on...\n"
     << "... it's only C++ ..." << endl;
```

```
From this point on...
... it's only C++ ...
```

We now create a ROOT histogram and fill it with random numbers distributed according to a Gaussian.

In [2]:
```
TH1F h("gauss","Example histogram",64,-4,4);
h.FillRandom("gaus");
```

Now, we create a canvas, the entity which holds graphics primitives.

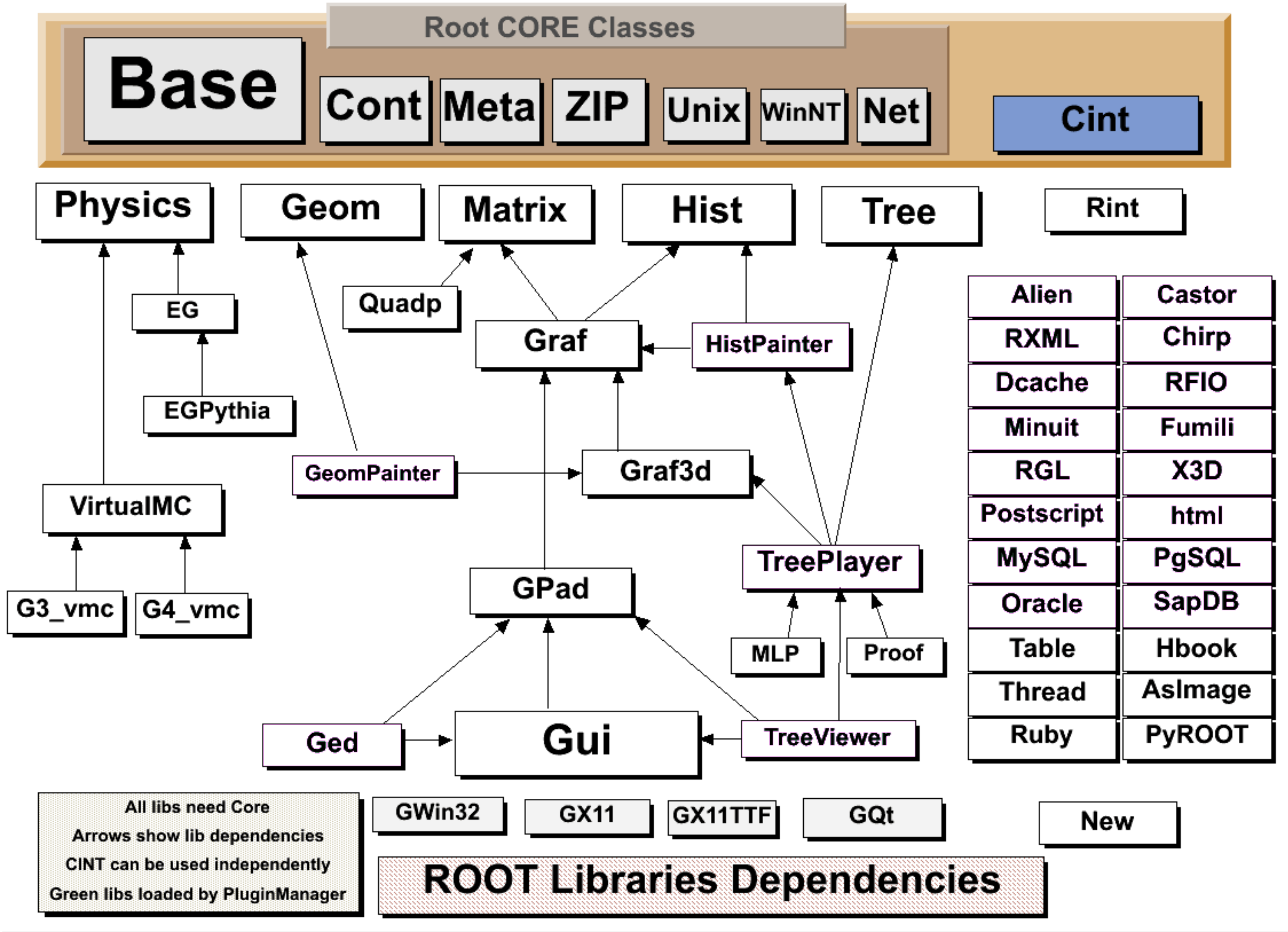
In [3]:
```
TCanvas c("myCanvasName","The Canvas Title",1600,1200);
h.Draw()
```

For the histogram to be displayed in the notebook, we need to draw the canvas.

In [4]:
```
c.Draw()
```

Much More …

In this talk, I presented the most basic classes typically used during physics analyses



ROOT contains many more libraries, and has several more applications