CSIC
Consejo Superior de Investigaciones Científicas

Universitat de València

IFIC Institut de Física Corpuscular

Excelencia Severo Ochoa

Introduction to ROOT
Practical Session

Luca Fiorini

IFIC Summer Student 2025

July 14th 2025

Contents

- **Practical introduction to the ROOT framework**
  - Starting ROOT
  - ROOT prompt
  - Macros
  - TBrowser
  - Functions
  - Histograms
  - Files
  - TTrees
  - Pyroot
- **Nomenclature**
  - **Blue: you type it**
  - **Red: you get it**

Macros and slides are in http://ific.uv.es/~fiorini/ROOTTutorial

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)

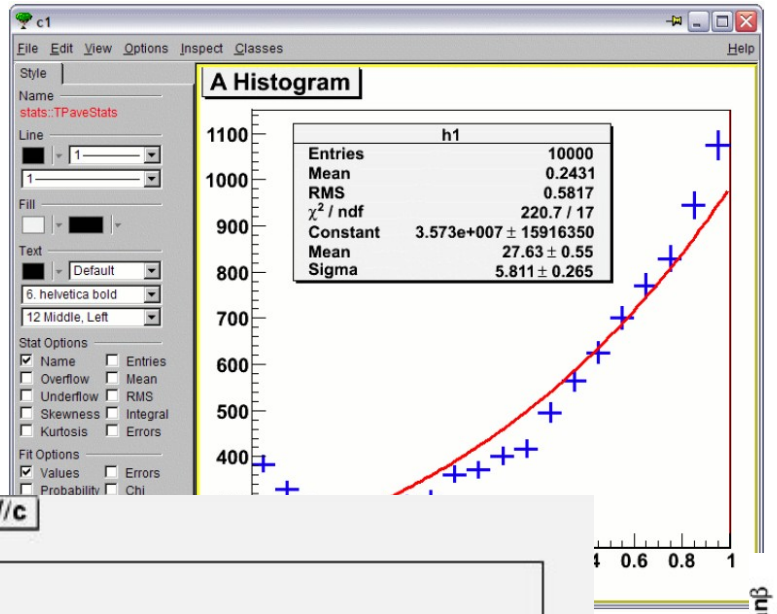
- **The user interacts with ROOT via a graphical user interface, the command line or scripts**
- **The command and scripting language is C++**
  - Embedded C++ interpreter CLING (ROOT6) based on LLVM and Clang libraries.
  - Large scripts can be compiled and dynamically loaded

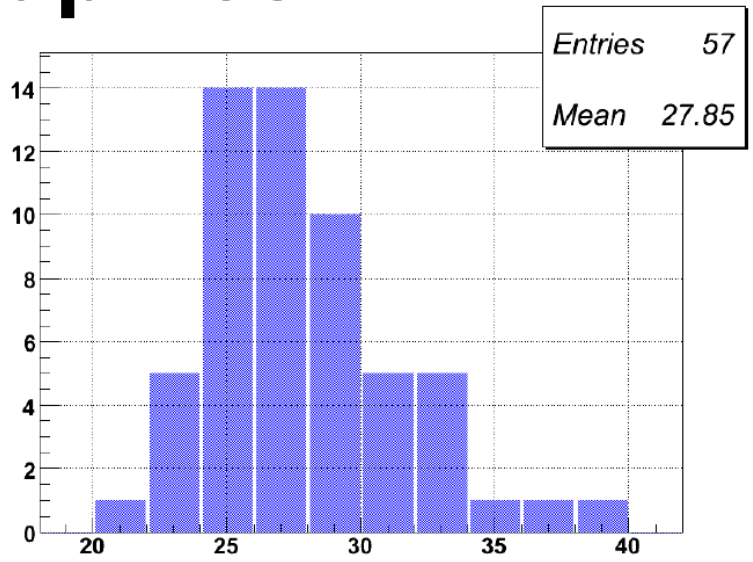
And for you?
ROOT is usually the interface (and sometimes the barrier) between you and the data

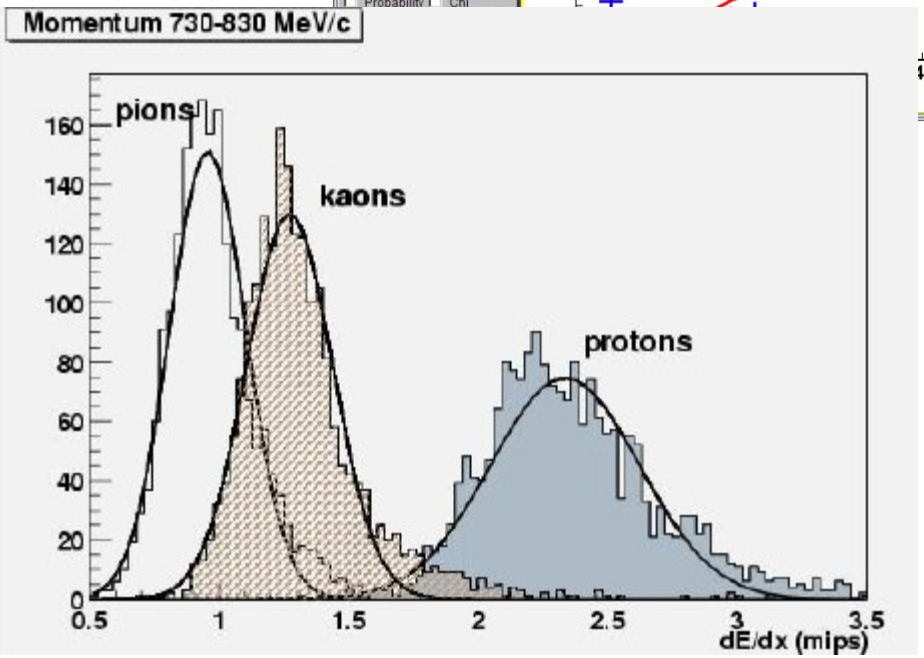
ROOT: An Open Source Project

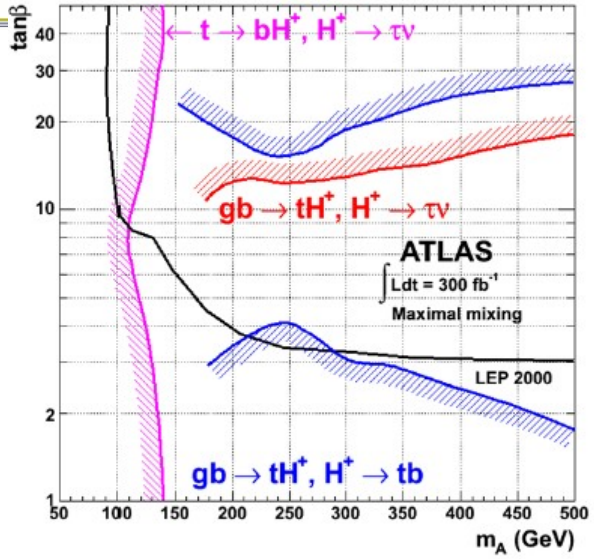
- **The project was started in Jan 1995**
- **First release Nov 1995**
- **The project is developed as a collaboration between:**
  - Full time developers:
    - 7 people full time at CERN (PH/SFT)
    - 2 developers at Fermilab/USA
  - Large number of part-time contributors (160 in CREDITS file)
  - 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

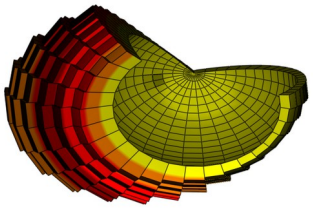


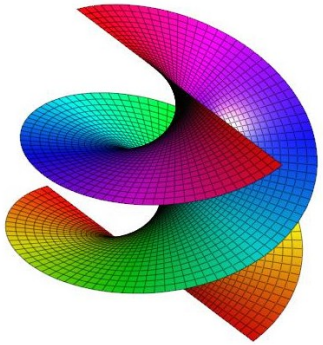


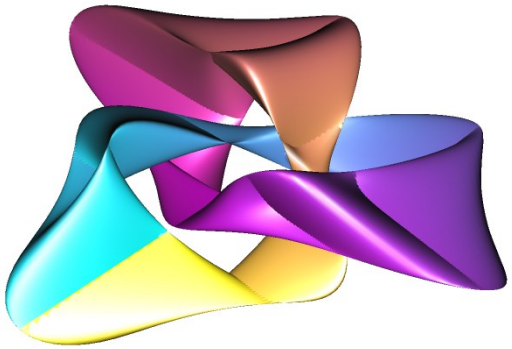


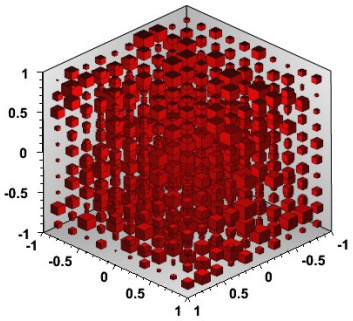


ROOT: Graphics



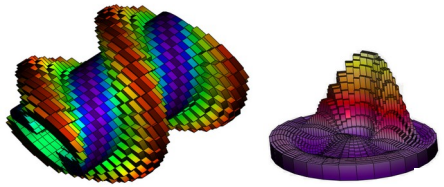


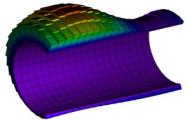


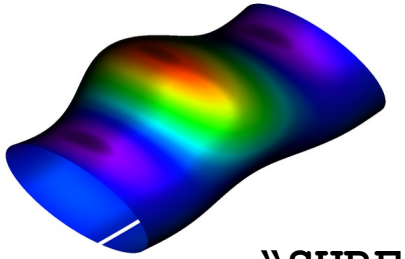


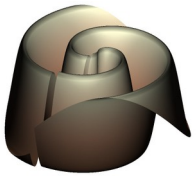
TH3

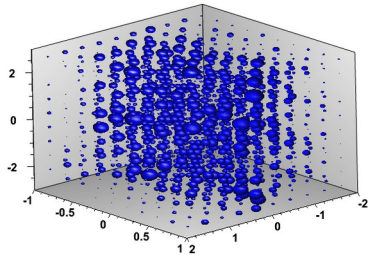
TGLParametric



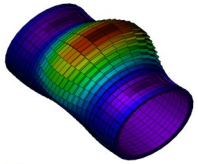




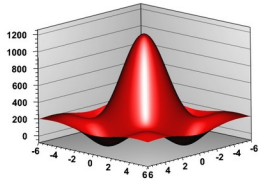


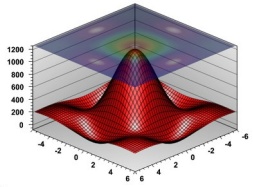


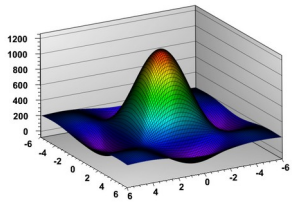
"LEGO"

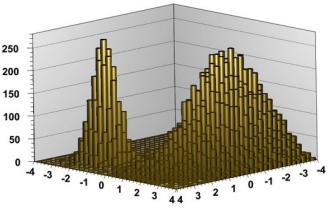


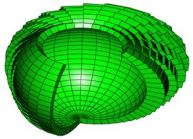
"SURF"





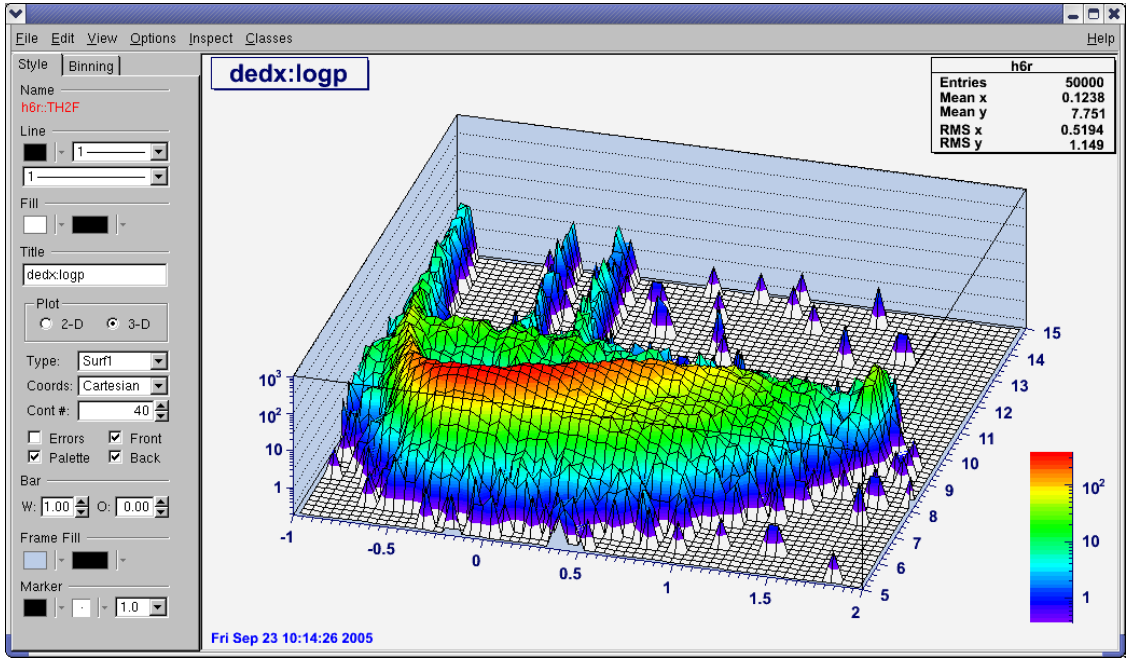


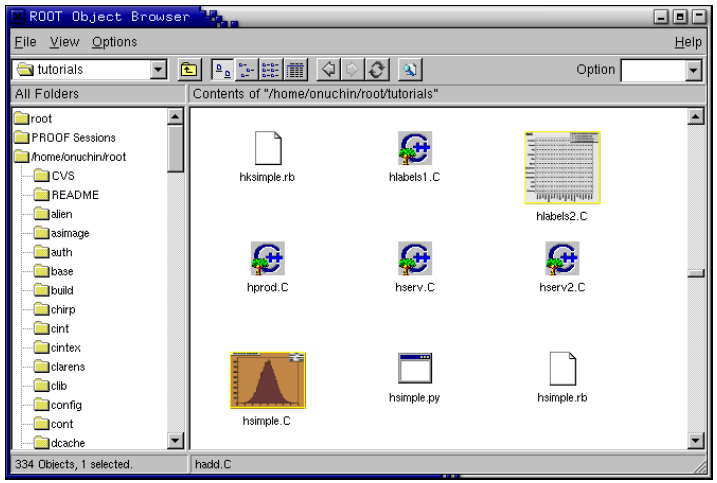


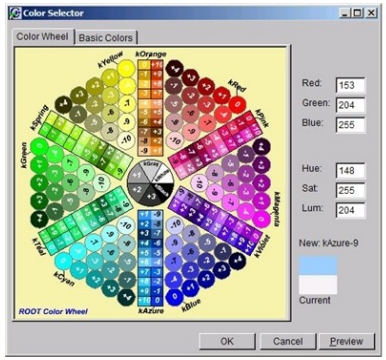


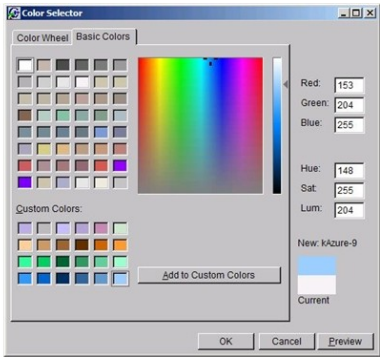
TF3

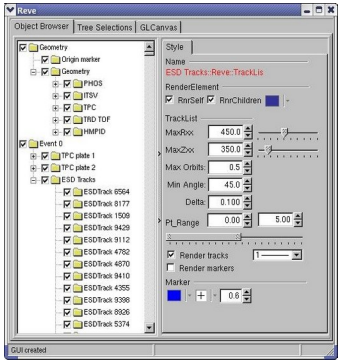
ROOT: Graphical Interfaces

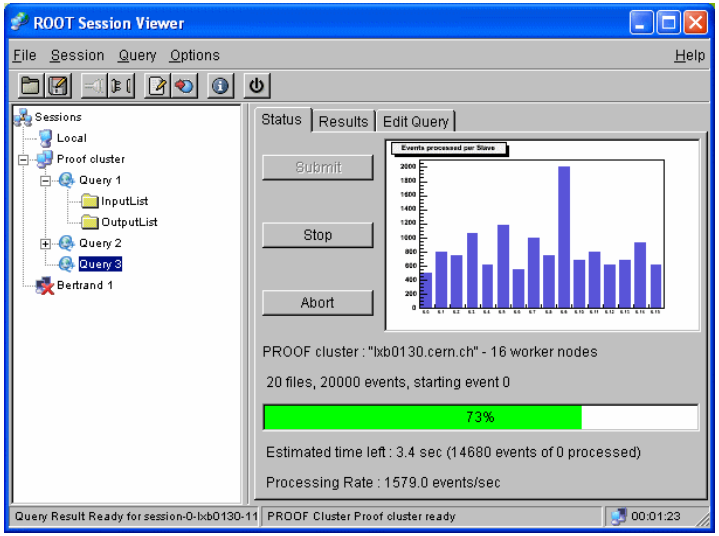




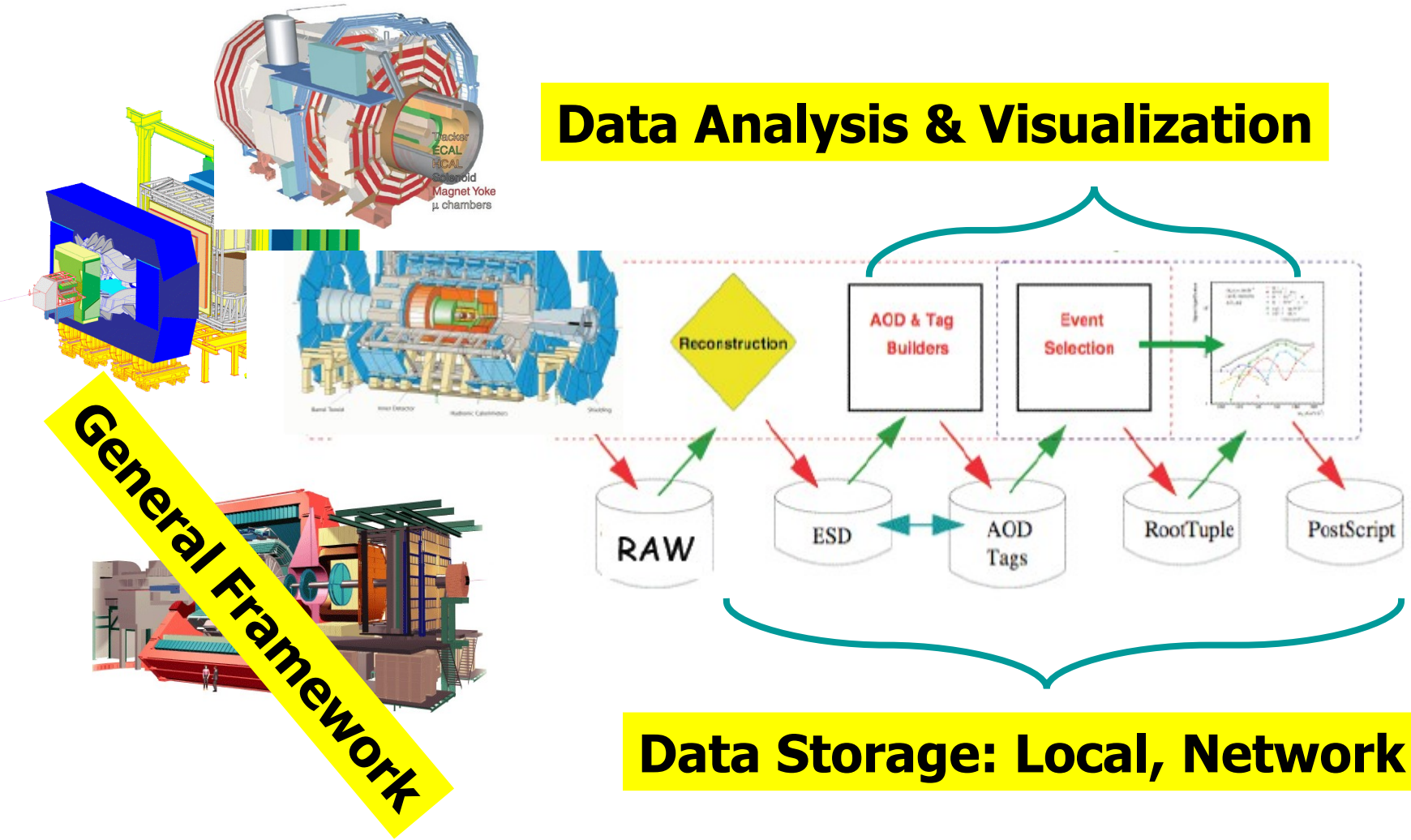




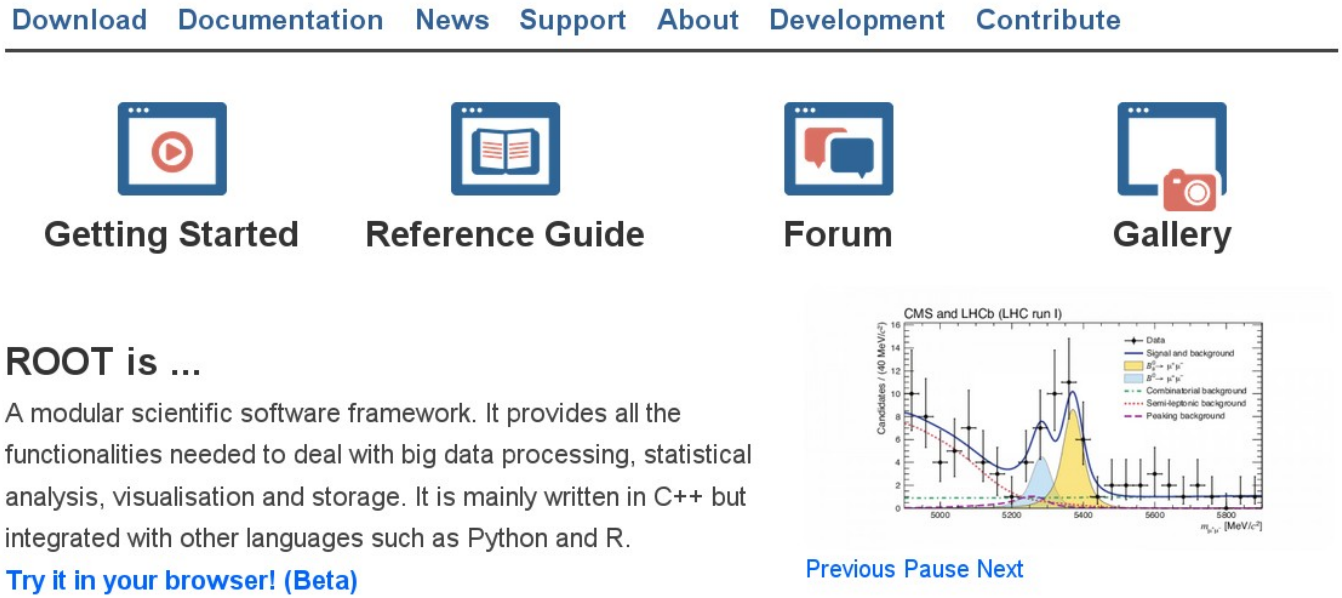




ROOT Application Domains



ROOT Download & Installation



- http://root.cern.ch
  - Binaries for common Linux PC flavors, Mac OS, Windows
- **Source files**

Before Installing ROOT, add dependencies, discussed here:
https://root.cern/install/dependencies/

  - Linux and MacOS: ROOT6 preferred
  - Windows: ROOT6 and ROOT5

If nothing works:
https://swan.web.cern.ch/

ROOT Resources

- **Main ROOT page**
  - http://root.cern.ch
- **Class Reference Guide**
  - https://root.cern/doc/master/
- **C++ tutorial**
  - http://www.cplusplus.com/doc/tutorial/
  - https://www.tutorialspoint.com/cplusplus/
- **Hands-on tutorials:**
  - https://root.cern.ch/learn/courses/
  - https://www.youtube.com/watch?v=s9PTrWOnDy8

ROOT Prompt

- Starting ROOT

$ root $ root -l (without splash screen) $ root -h

$ root --web=off

- The ROOT prompt – a nice calculator

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

- Command history
  - Scan through with arrow keys ↑↓
  - Search with CTRL-R (like in bash)
- Built-in commands:

```
root [ ]  .?   //or .help      root [ ] .help TF1
```

- 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 (int i=10; i>0; i--) {cout << i <<
  endl;}; cout << “BOOM!!” << endl;

  or

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

- Aborting wrong input

  root [ ] printf("%d\n, i)
  (cont'ed, cancel with .@) [] .@

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

ROOT Macros

- It is quite cumbersome to type the same lines again and again
- Create macros with text editor for most 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)`
- Or `root [0] .L myfirstmacro.C`
  `root [1] myfirstmacro(10)`
  `> root -l myfirstmacro.C(10)`

Macros

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

For example: macro1.C

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

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

- Executing macros

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

Compile Macros – Libraries

- "Library": compiled code, shared library
- CINT/CLING can call its functions!
- Building a library from a macro: ACLiC (link)
  (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

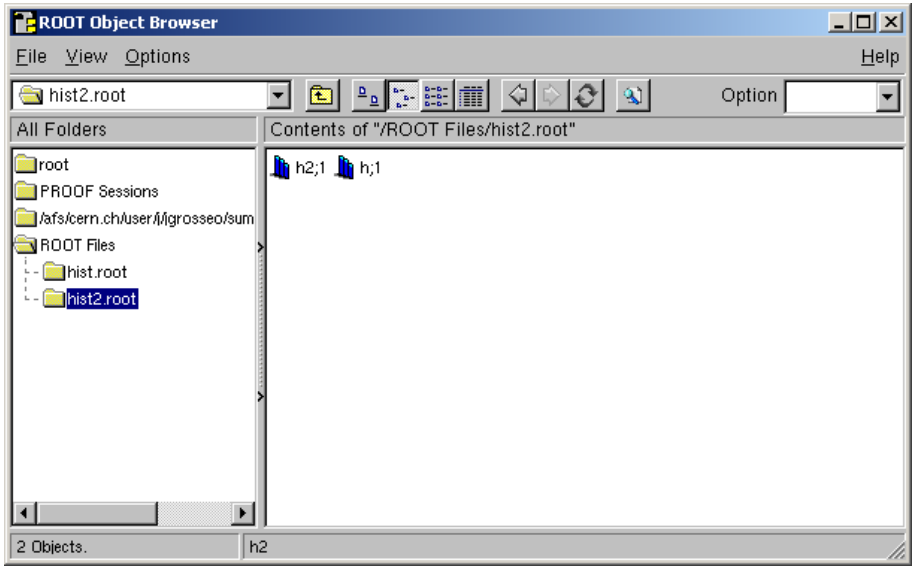
Compiled vs. Interpreted

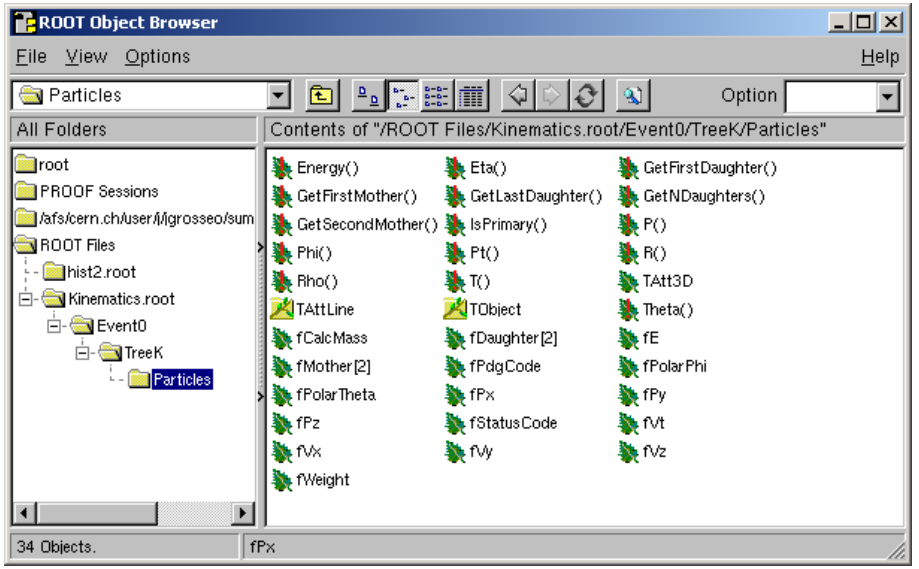
- **Why compile?**
  - Faster execution, CINT/CLING has some limitations…
- **Why interpret?**
  - Faster Edit → Run → Check result → Edit cycles ("rapid prototyping"). Scripting is sometimes just easier
- **So when should I start compiling?**
  - For simple things: start with macros
  - Rule of thumb
    - Is it a lot of code or running slow? → Compile it!
    - Does it load C++ standard library → Compile it!
    - Does it behave weird? → Compile it!
    - Is there an error that you do not find → Compile it!

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





Functions

- The class TF1 allows to create 1D functions

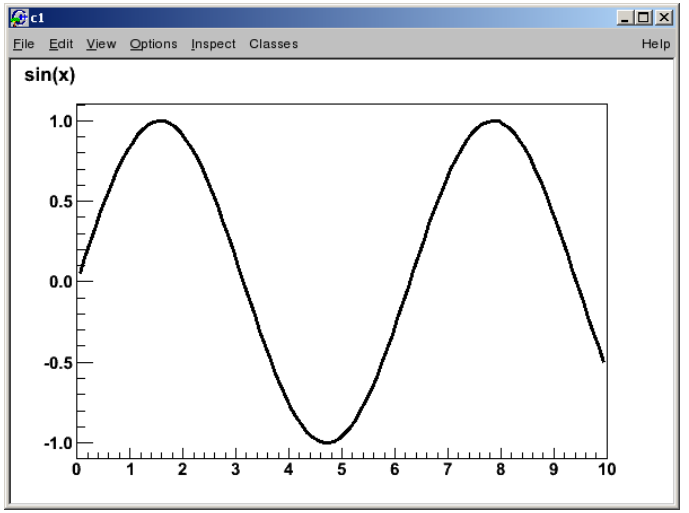
  root [ ] f = new TF1("func", "sin(x)", 0, 10)

  – "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(kBlue)

- 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

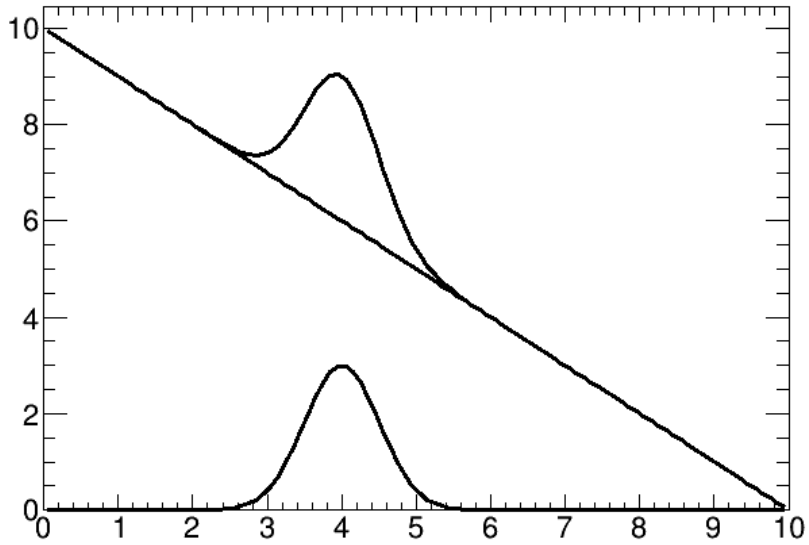
```
root [ ] TF1 f2("func", "cos(x)", 0, 10)
```

- One can point to the other

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

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)**

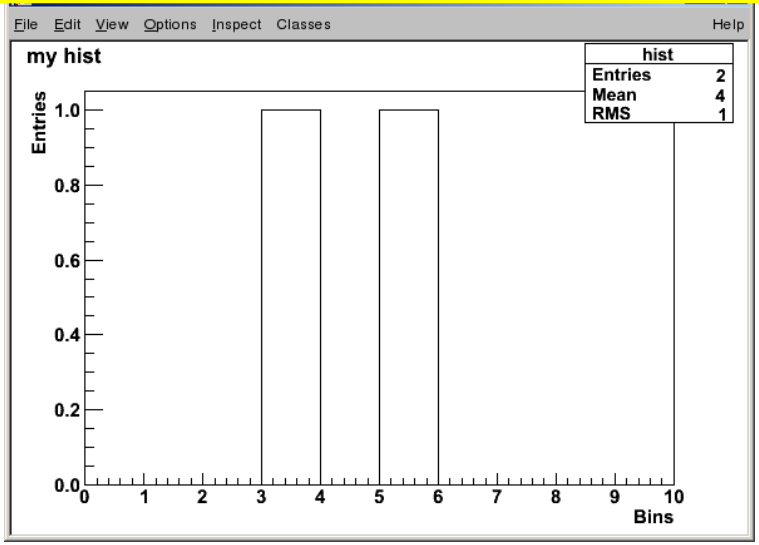
  root [ ] **h = new TH1F("hist", "my hist;Bins;Entries", 10, 0, 10);**
  - "hist" is a (unique) name
  - "my hist;Bins;Entries" are the title and the x and y labels
  - 10 is the number of bins
  - 0, 10 are the limits on the x axis. Thus the first bin is from 0 to 1, the second from 1 to 2, etc.

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

- **Fill the histogram**

  root [ ] h->Fill(3.5);
  root [ ] h->Fill(5.5);
- **Draw the histogram**

  root [ ] h->Draw();



- **code in hist.C**

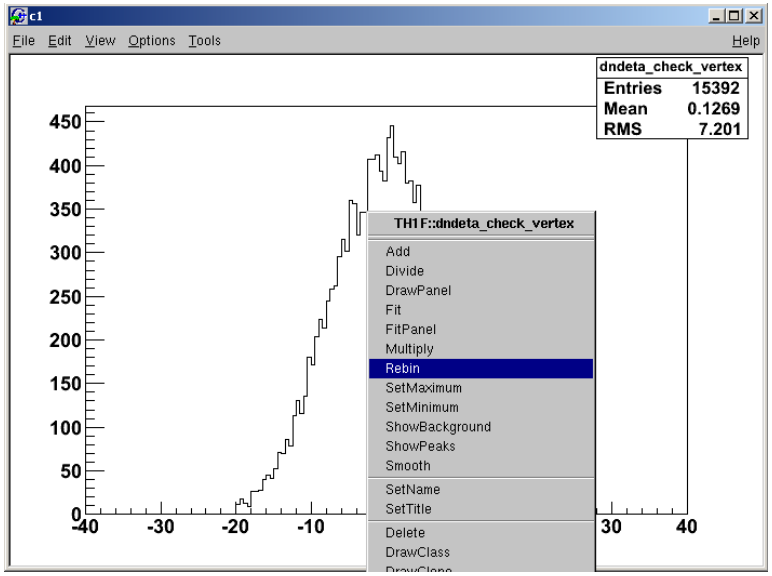
Histograms (2)

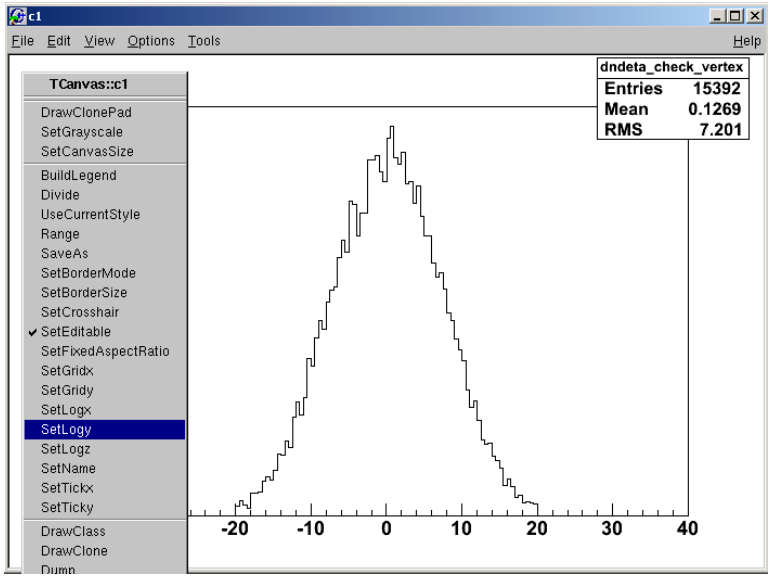
```
root [ ] TH1F h("h","h",80,-40,40)
root [ ]  TRandom r;
root [ ] for (int i=0;i<15000;i++) { h.Fill(r.Gaus(0,7));}
root [ ] h.Draw()
```

- **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()
  ```



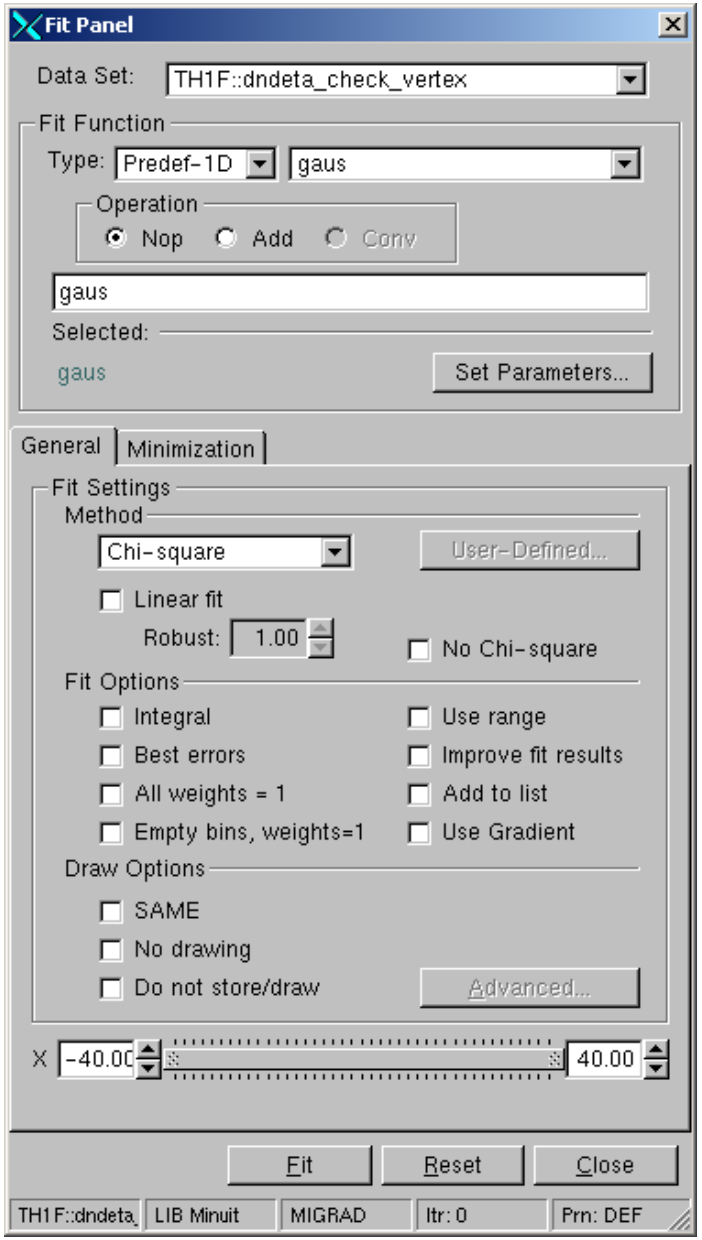


- **try to run .x hist2a.C //what happens?**
- **Now try to run .x hist2b.C //what changes?**

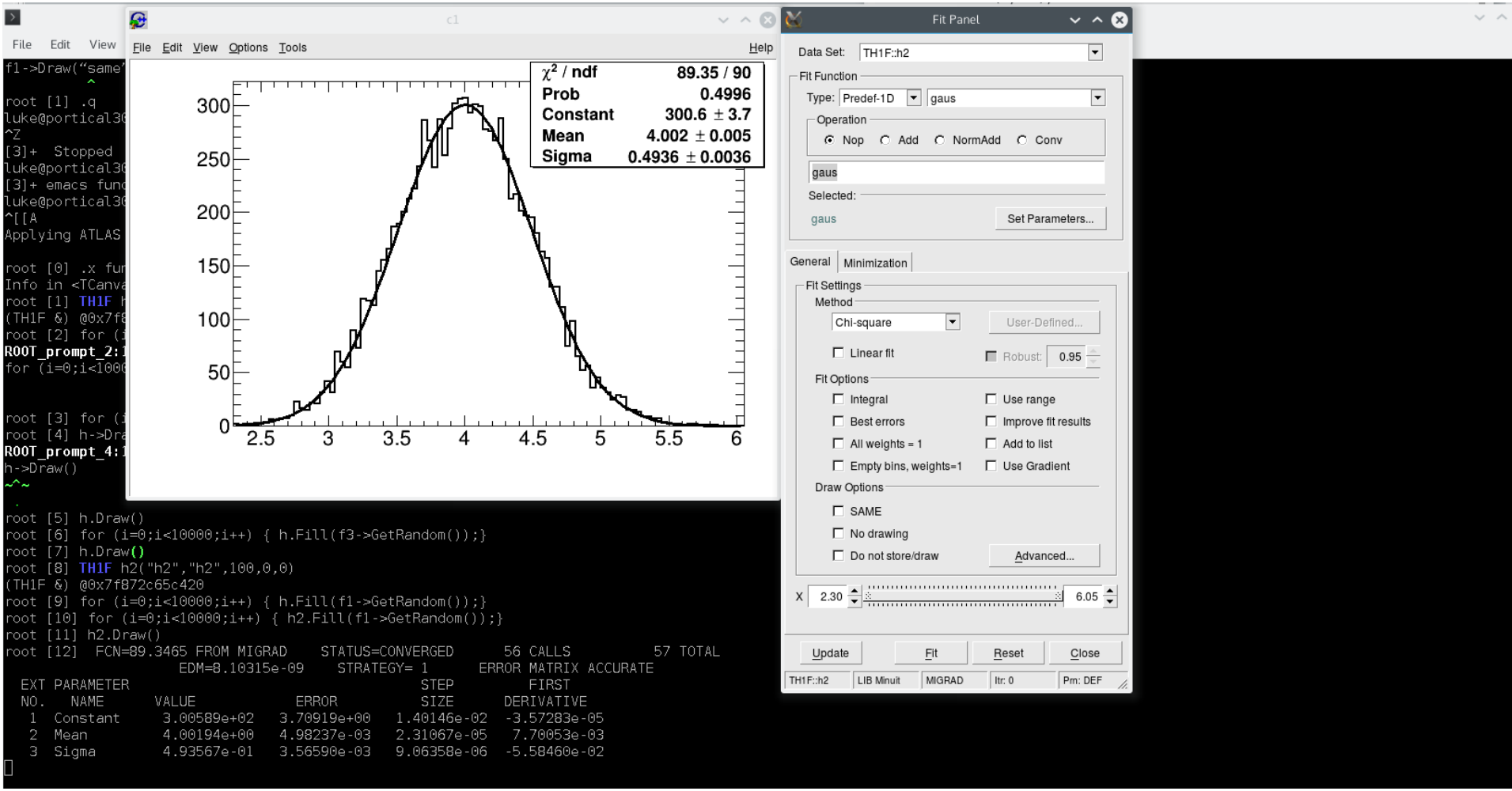
Fitting Histograms

- **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.

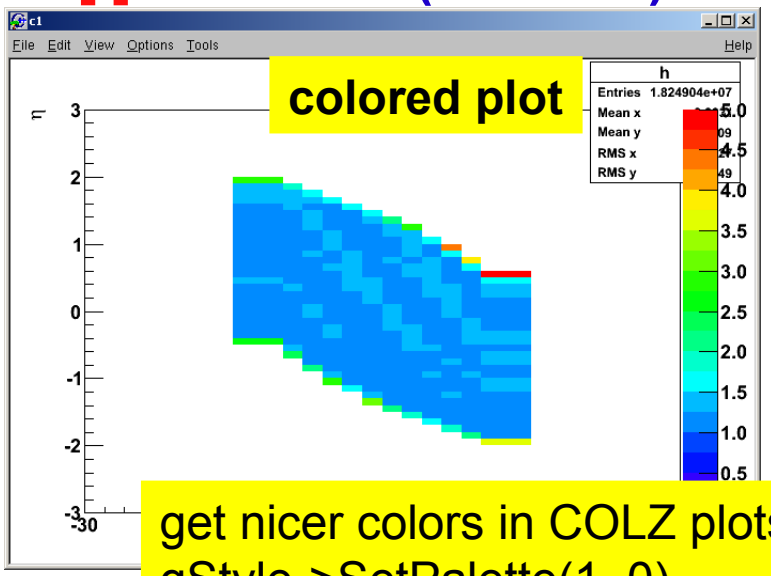


Fitting Histograms

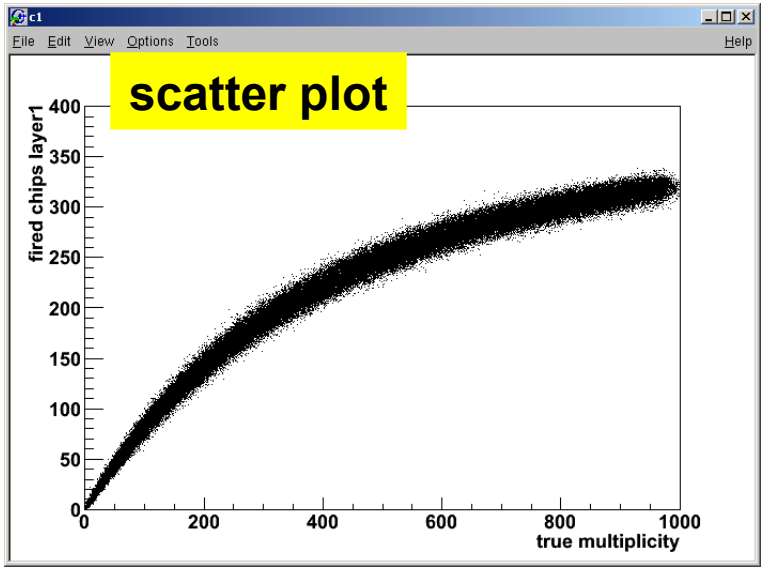


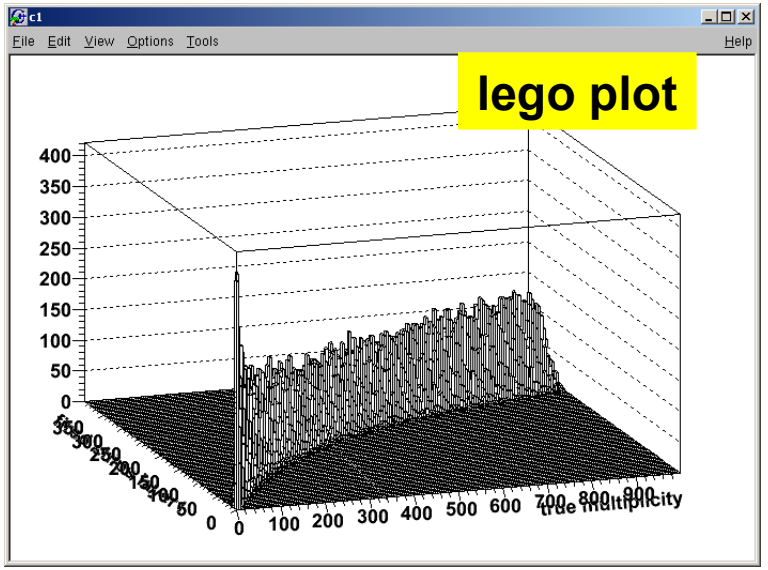
2D Histograms

```
root -l hist2.root
root [ ] TBrowser a
root [ ] h->Draw()
root [ ] h->Draw("LEGO")
root [ ] h2->Draw("COLZ")
```



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





NB: h and h2 are inside file hist2.root

Files

- The class TFile allows to store ROOT objects 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

etc.

- 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 (**IMPORTANT!**)

```
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
  root [ ] new TBrowser //it opens a browser
- **Open a file when starting root**
  $ root file.root
  – Access it with the _file0 or gFile pointer

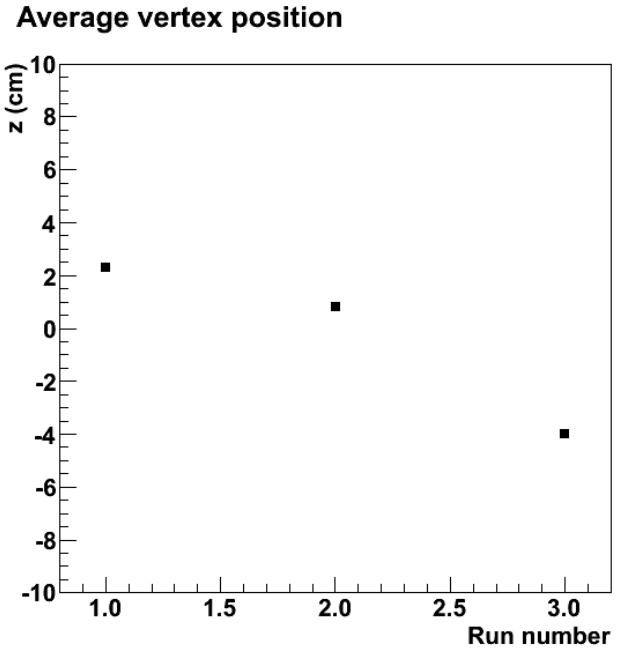
➔ **Object ownership**
After reading an object from a file don't close the file! Otherwise your object is not in memory anymore

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 Example

```
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");
```



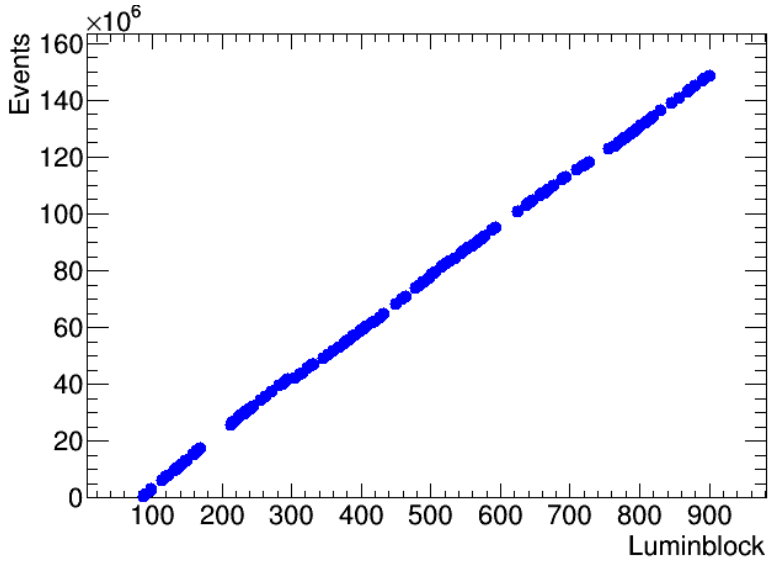
- try to run .x graph.C

Graphs (2)

- try to run .x graph2.C

Graph2 Contents

```
graph = new TGraph("data.txt");
graph->Draw("AP");
graph->SetMarkerStyle(20);
graph->SetMarkerColor(4);
graph->GetXaxis()->SetTitle("Luminblock");
graph->GetYaxis()->SetTitle("Events");
graph->SetTitle("Number of Events");
```



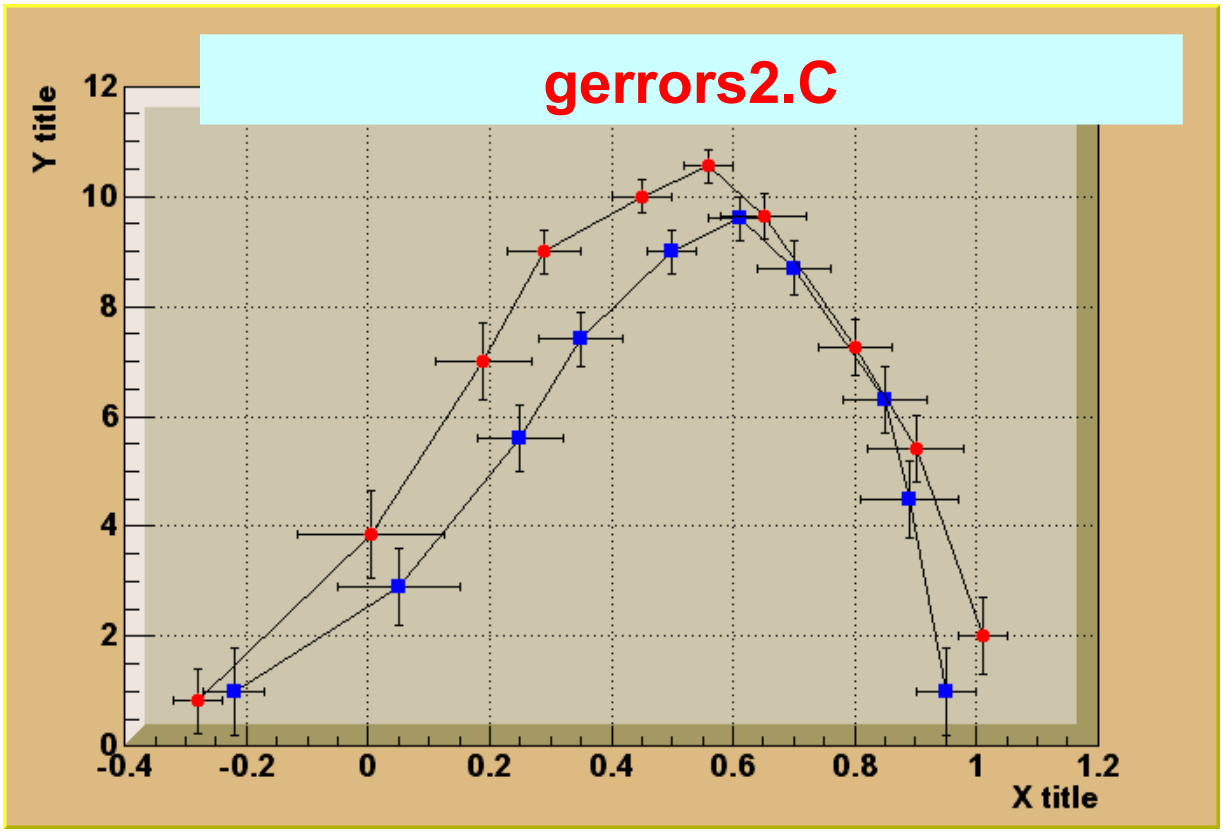
Graphs (3)

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

TGraph(n,x,y)

TCutG(n,x,y)

TMultiGraph



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

Graphs Fit

- try to run .x graphfit.C

graphfit Contents

Line 13: the name of the main function (it plays the role of the "main" function in compiled programs). It has to be the same as the file name without extension.

Line 24-25: instance of the TGraphErrors class.

Line 33: the canvas object that will host the drawn objects. The "memory leak" is intentional, to make the object existing also out of the macro scope.

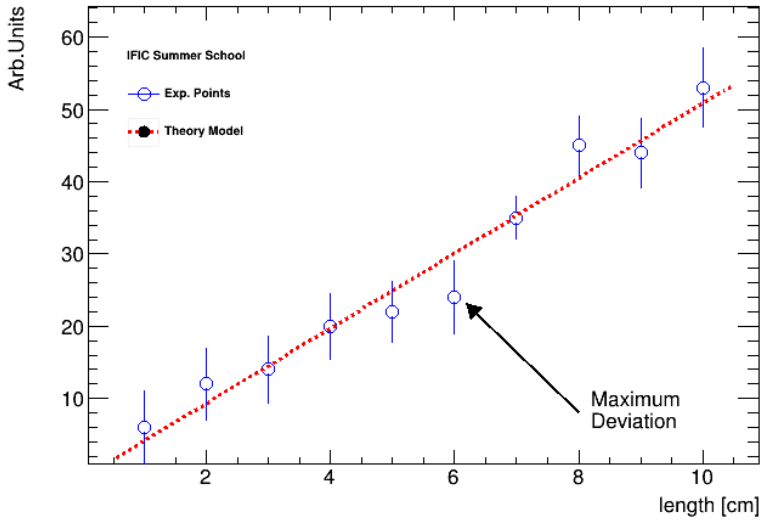
Line 36: the method DrawClone draws a clone of the object on the canvas. It has to be a clone, to survive after the scope, and be displayed on screen after the end of the macro execution.

Line 39: define a mathematical function.

Line 43: fits the f function to the graph. Look at the output on the screen to see the parameters values.

Line 47-52: completes the plot with a legend,

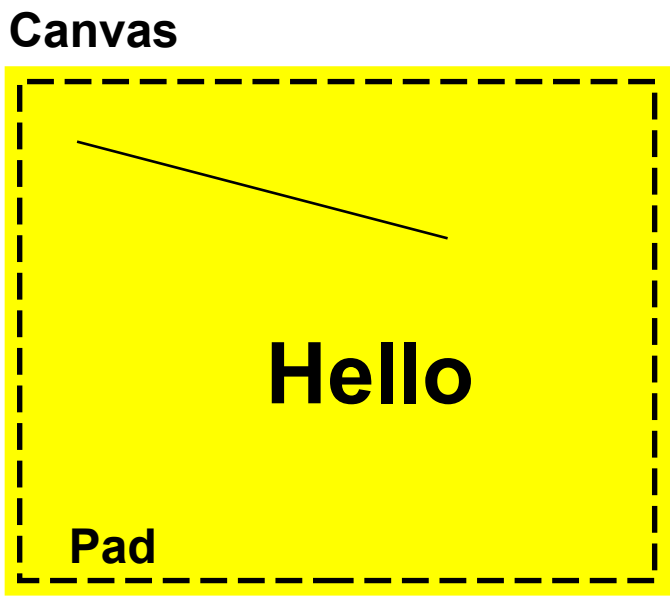
Line 63: save the canvas as image. The format is automatically inferred from the file extension (it could have been eps, gif, …).



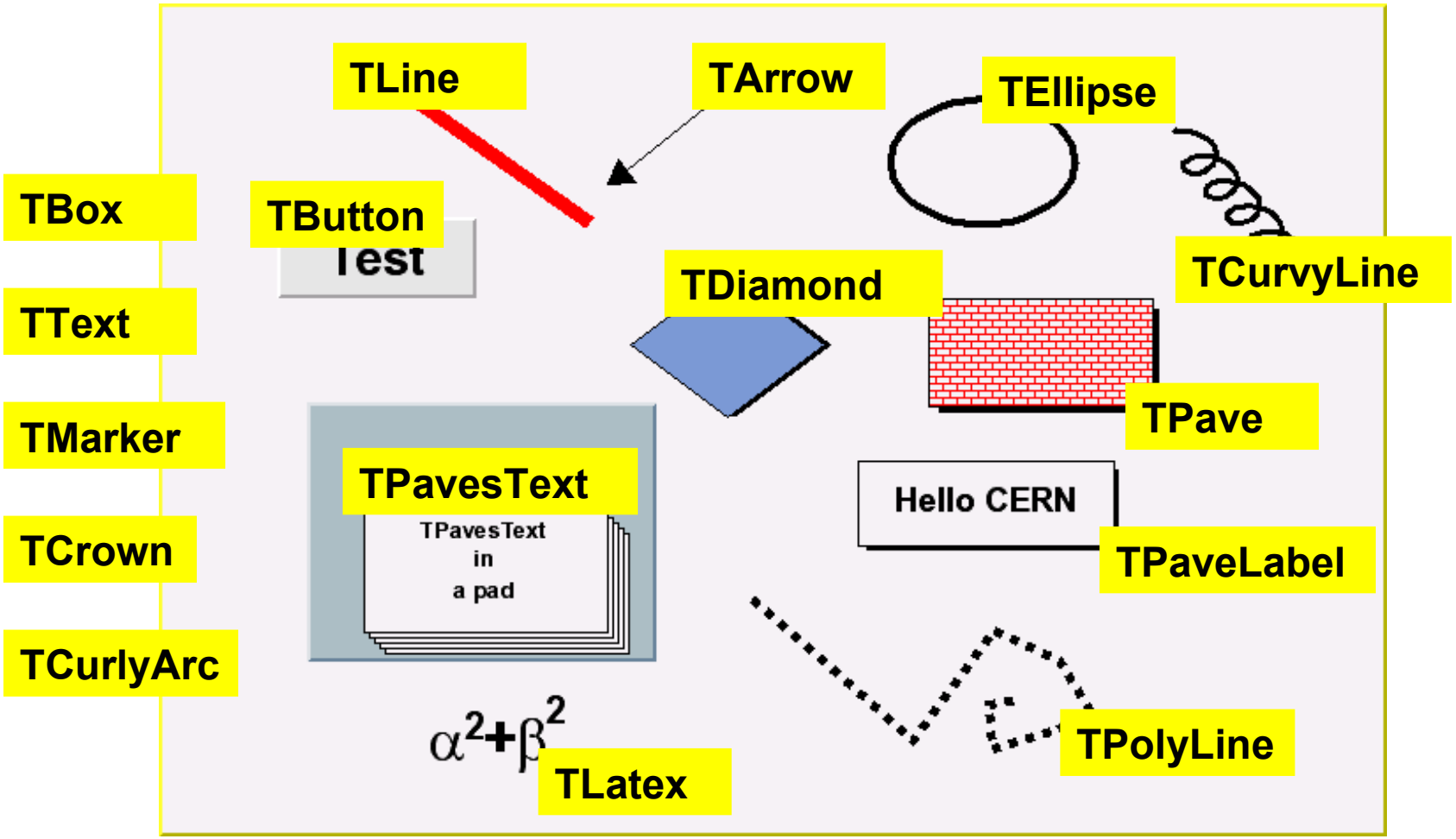
Graphics Objects

- 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()
```

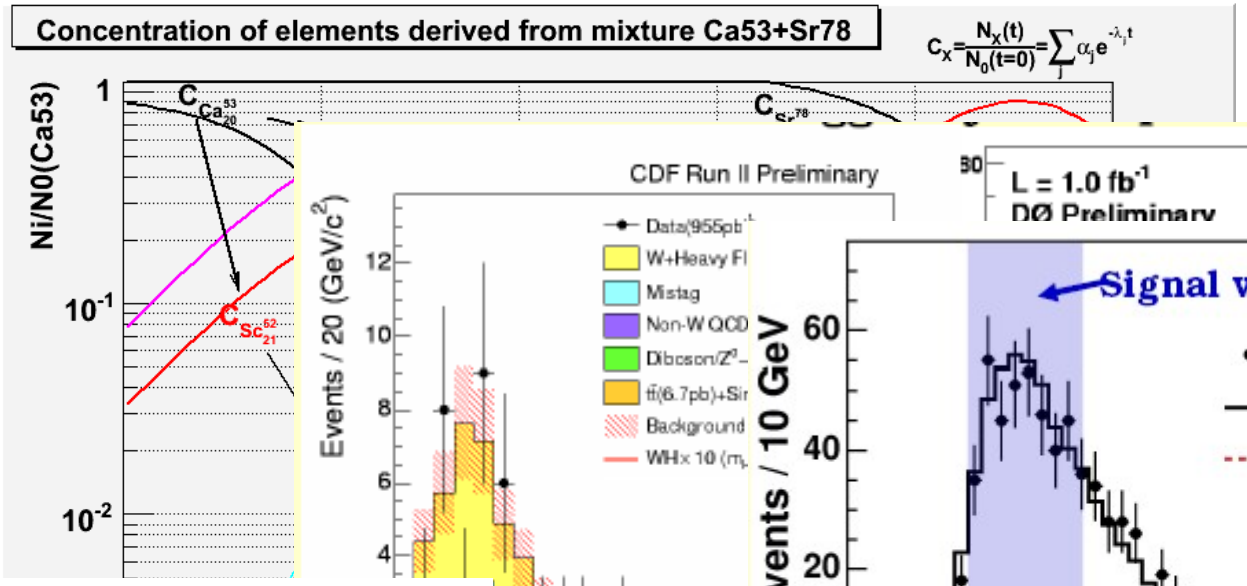


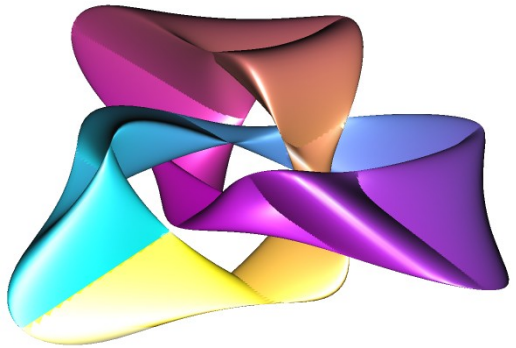
More Graphics Objects



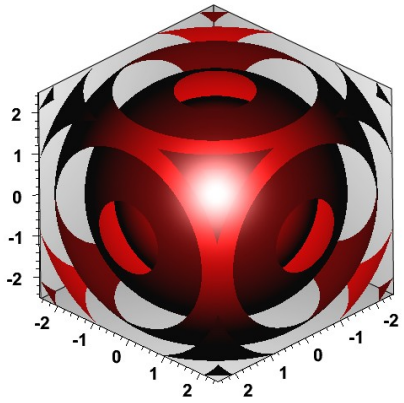
Can be accessed with the toolbar
View → Toolbar (in any canvas)

Graphics Examples





TGLParametric



TF3

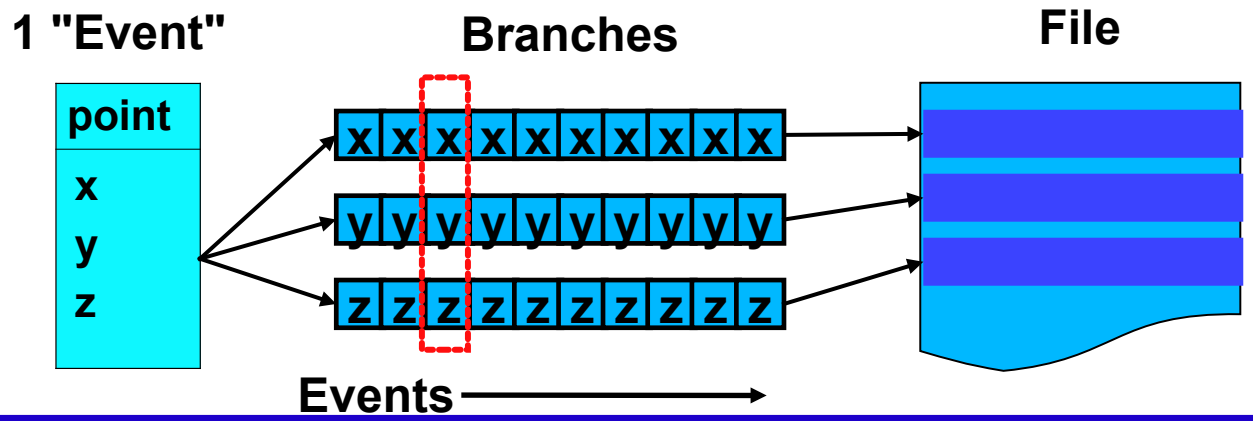
What is a ROOT Tree?

- **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, int, Float_t, ...)

When reading a tree, certain branches can be switched off
→ speed up of analysis when not all data is needed



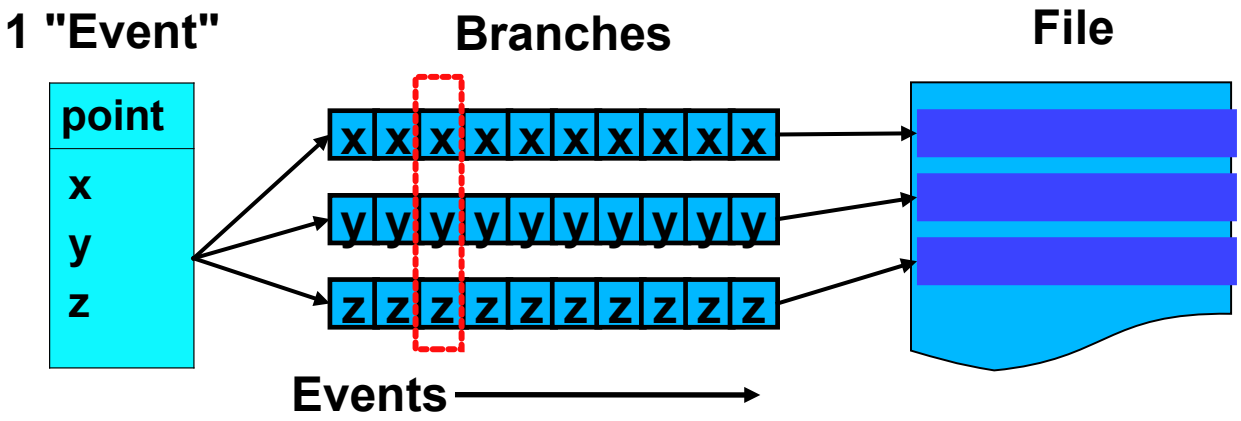
Trees

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



TTree - 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”);
```

- try to run .x simpletree.C

TTree - Writing

Fill the TTree

TTree::Fill copies content of member as new entry into the tree

```
root [ ] var1=5; var2=3.1; var3=10.;
root [ ] t->Fill();
root [ ] var1=1; var2=7; var3=4.5;
root [ ] t->Fill();
```

Inspect the tree

Flush the tree to the file

close the file

```
root [ ] t->Print();
root [ ] t->Show(1);

root [ ] t->Write();
root [ ] f->Close();
```

Code is in:
simpletree.C

TTree - 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;
}
```

Code is in: readtree.C

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

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)**

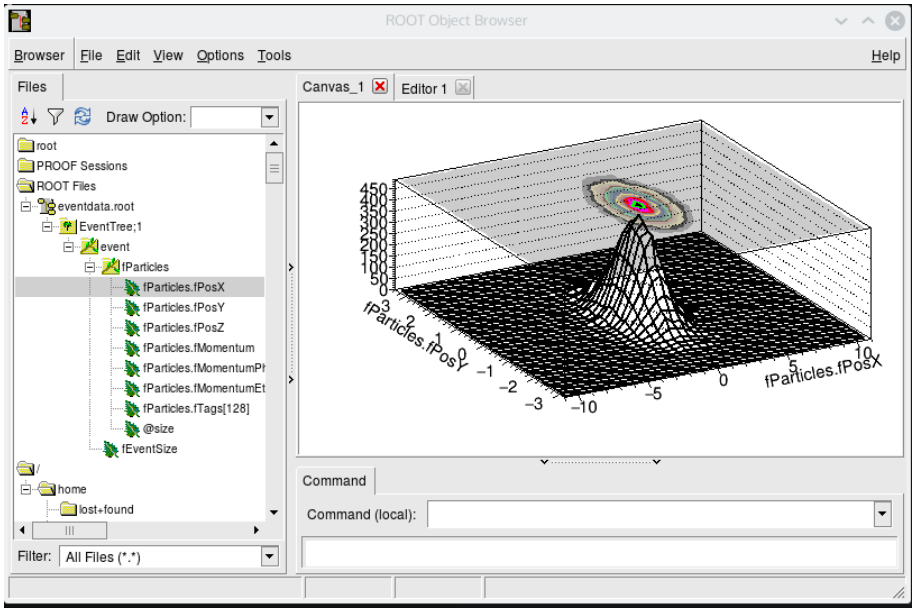
```
$ root eventdata.root
root [ ] tree->Scan();
root [ ] tree->Scan("*");
root [ ] tree->Scan("fParticles.fPosX:fParticles.fPosY:fParticles.fPosZ");
root [ ] tree->Scan("fParticles.fPosX:fParticles.fPosY:fParticles.fPosZ",
    "fParticles.fPosX<0")
```

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



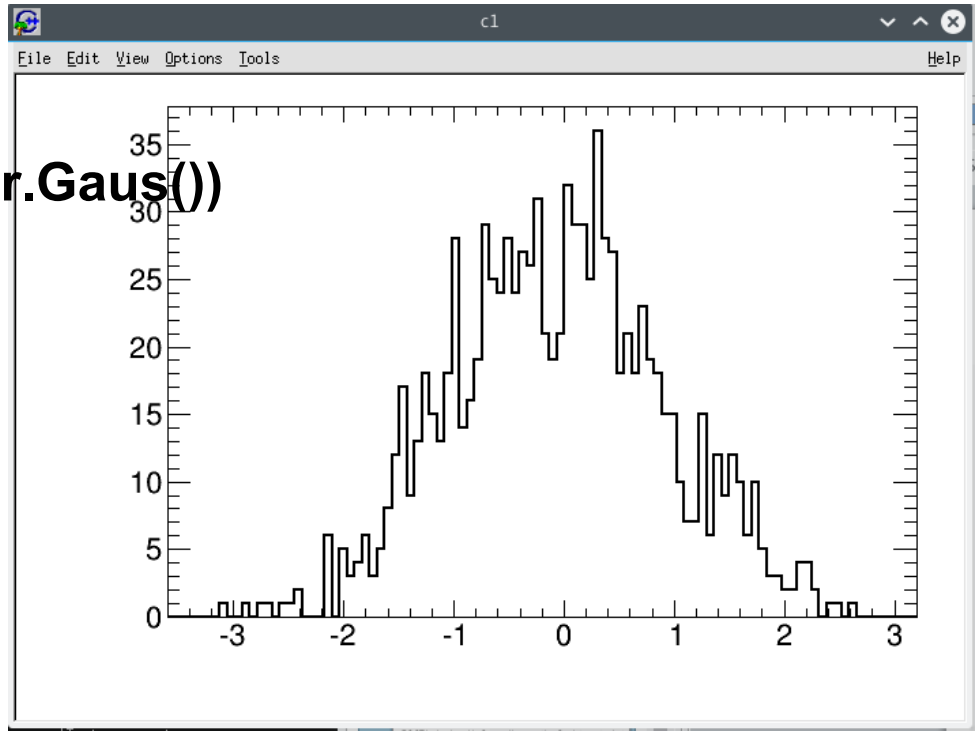
PyRoot

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

Open (i)python (use “pyroot” in Windows:

```
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!



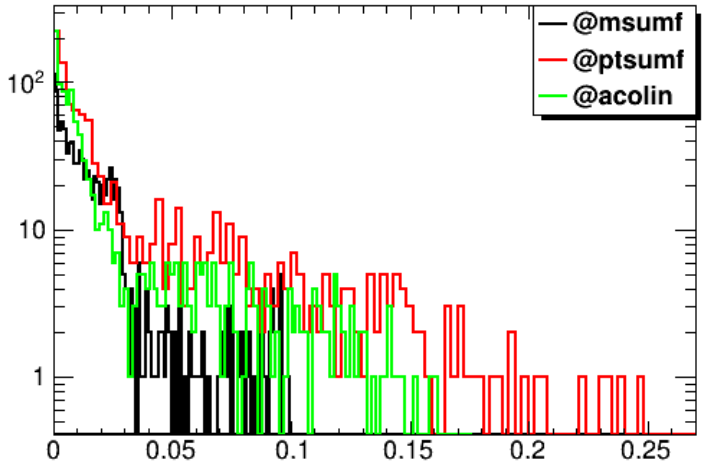
Machine Learning

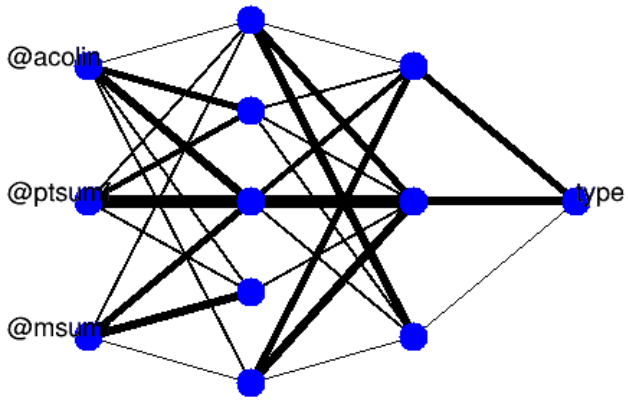
- Example of advanced statistical analysis:
  - Read from a tree the event variables for:
    - "signal" process, e.g. a simulation of a new phenomena you are looking for.
    - simulation of a "background process you want to separate the signal from.
  - Build a Neural Network with these variables, 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

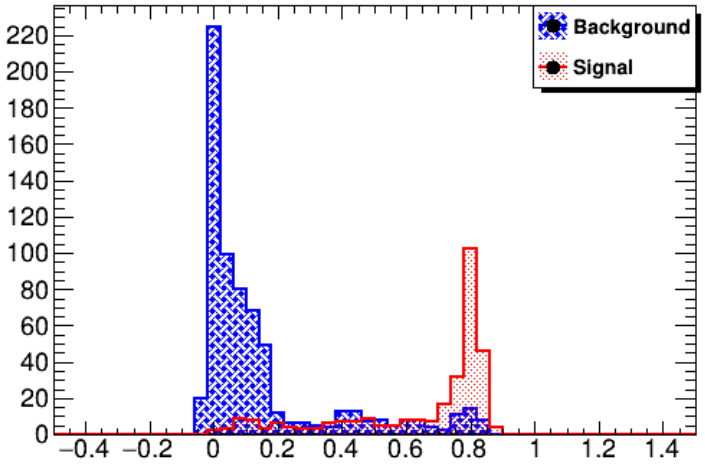
mlpHiggs.root file:

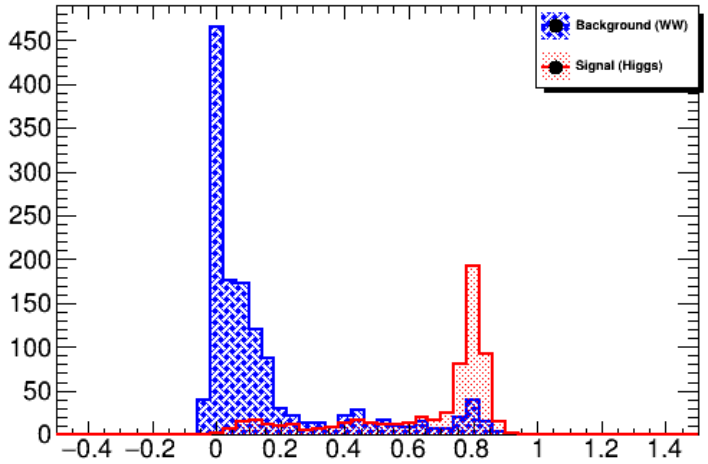
TFile::Open("http://root.cern.ch/files/mlpHiggs.root")

Machine Learning



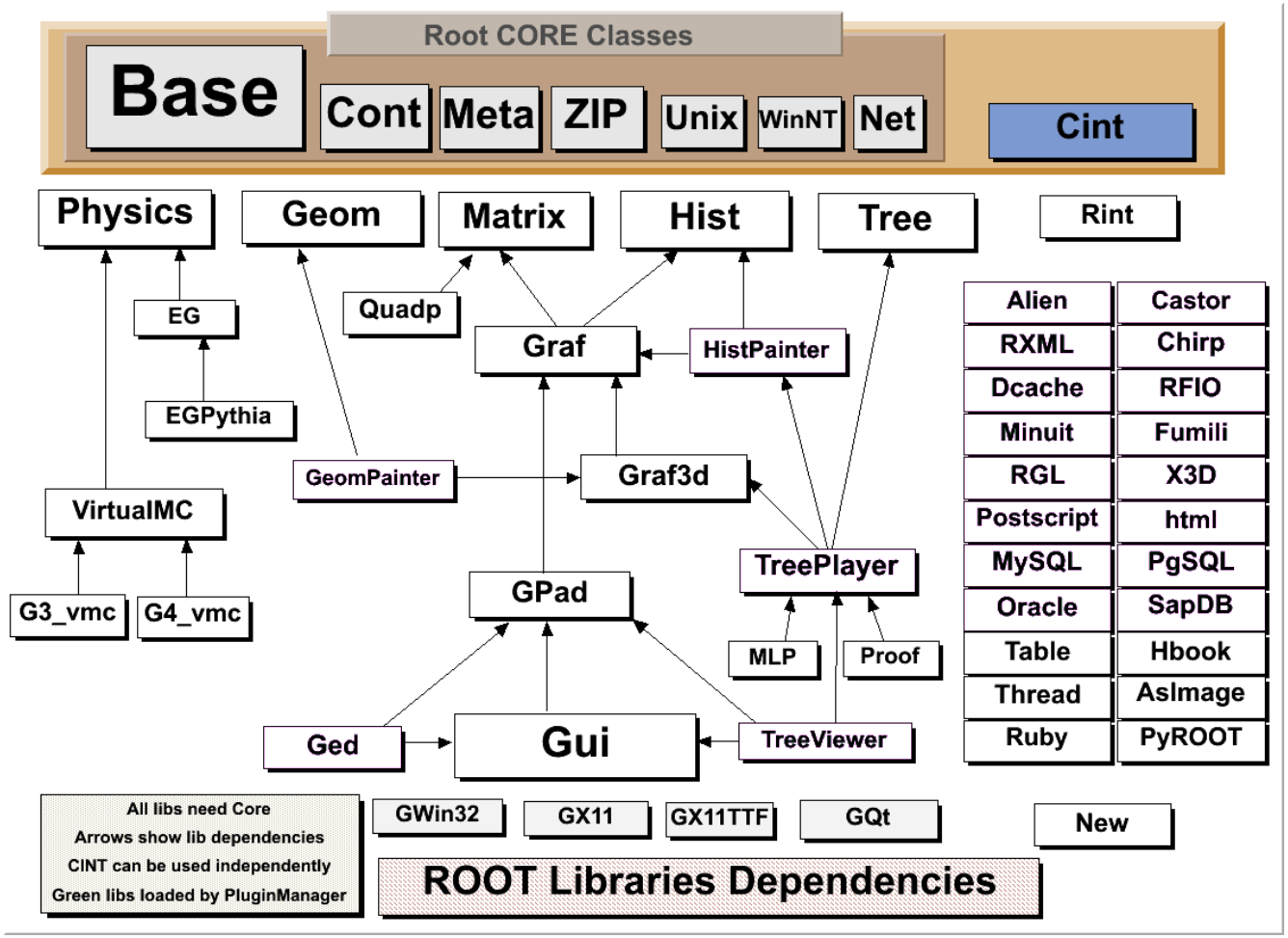






ROOT is MUCH more

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



ROOT contains many more libraries, and has several more applications