Introduction to ROOT
Practical Session

ROOT Data Analysis Framework

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  - Starting ROOT
  - ROOT prompt
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  - Files
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  - TBrowser
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- **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)

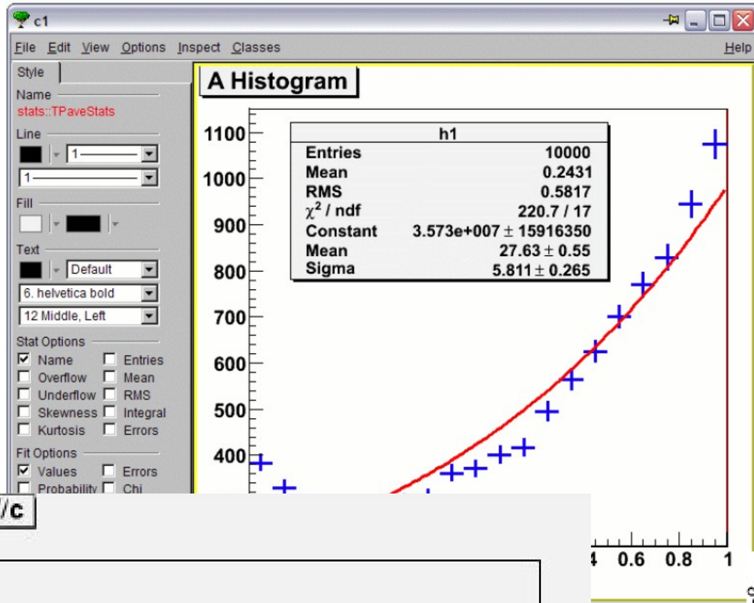
- **The user interacts with ROOT via a graphical user interface, the command line or scripts**
- **The command and scripting language is C++**
  - Embedded C++ interpreter CINT (ROOT5)/ CLING (ROOT6)
  - Large scripts can be compiled and dynamically loaded

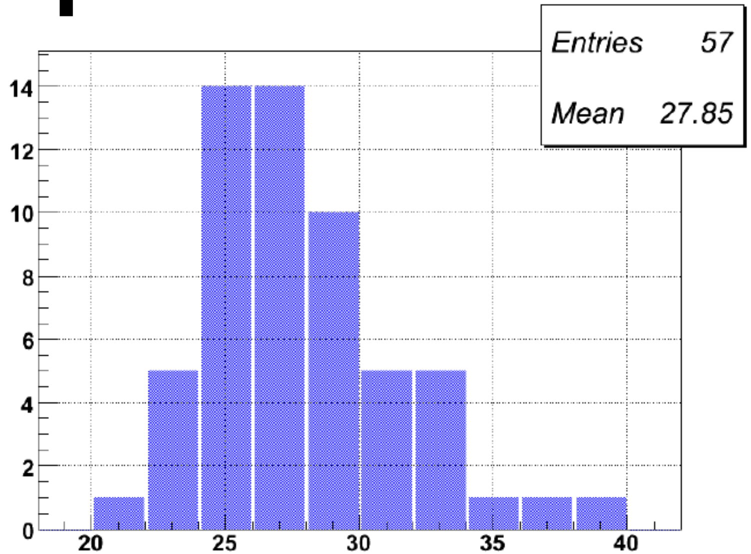
And for you?
ROOT is usually the interface (and sometimes the barrier) between you and the data

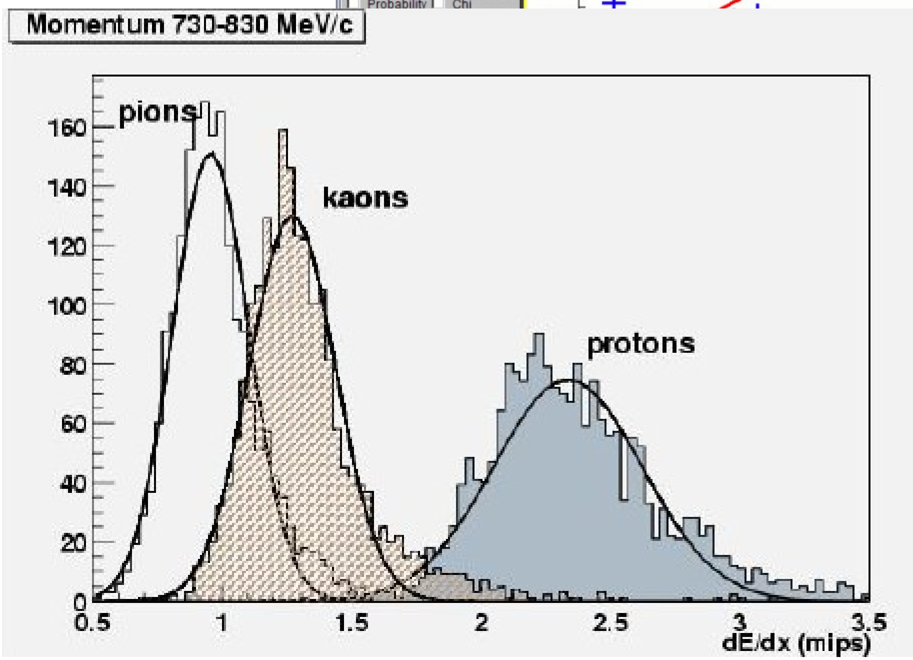
ROOT: An Open Source Project

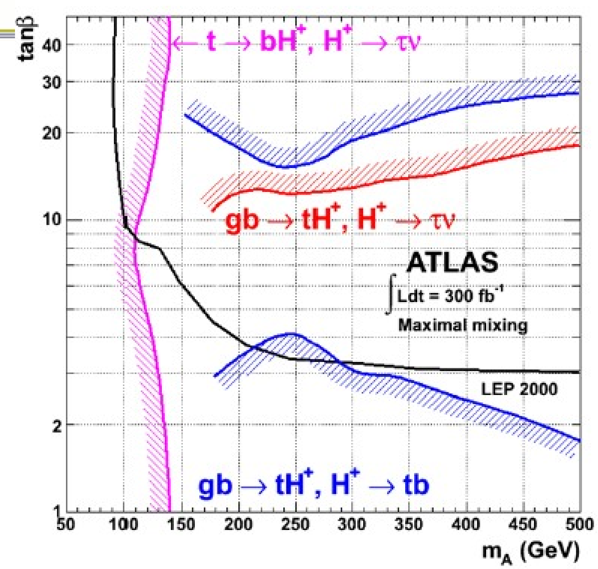
- **The project was started in Jan 1995**
- **First release Nov 1995**
- **The project is developed as a collaboration between:**
  - Full time developers:
    - 7 people full time at CERN (PH/SFT)
    - 2 developers at Fermilab/USA
  - Large number of part-time contributors (160 in CREDITS file)
  -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

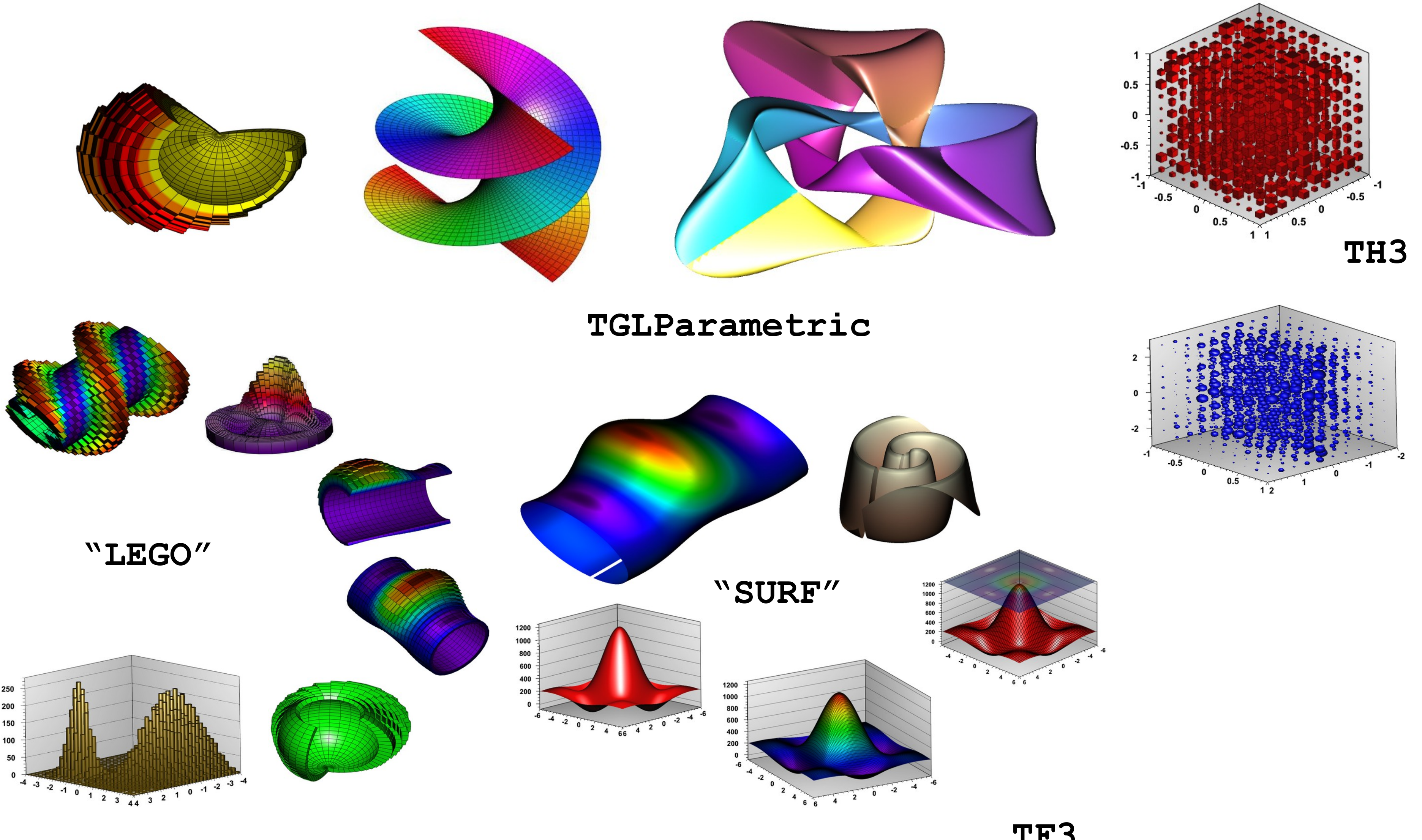




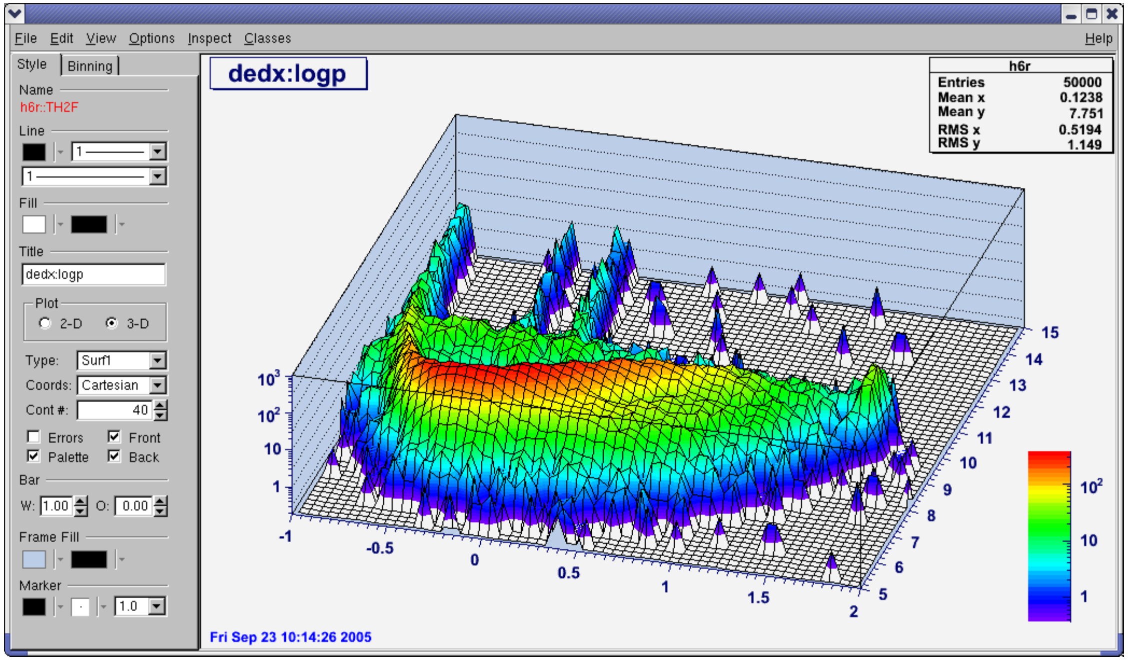


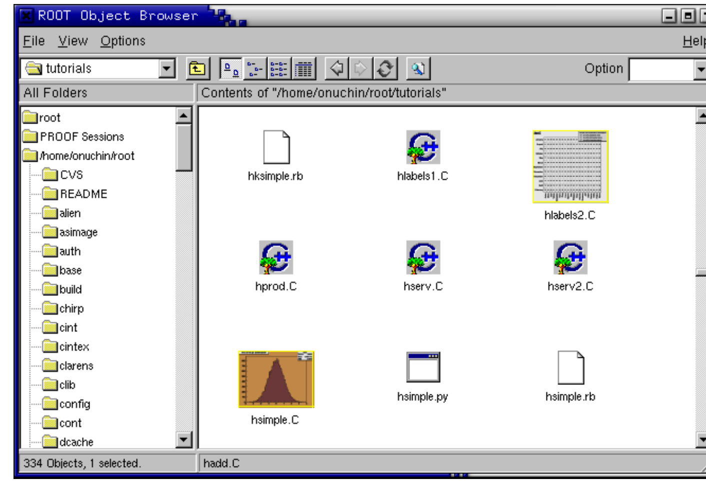


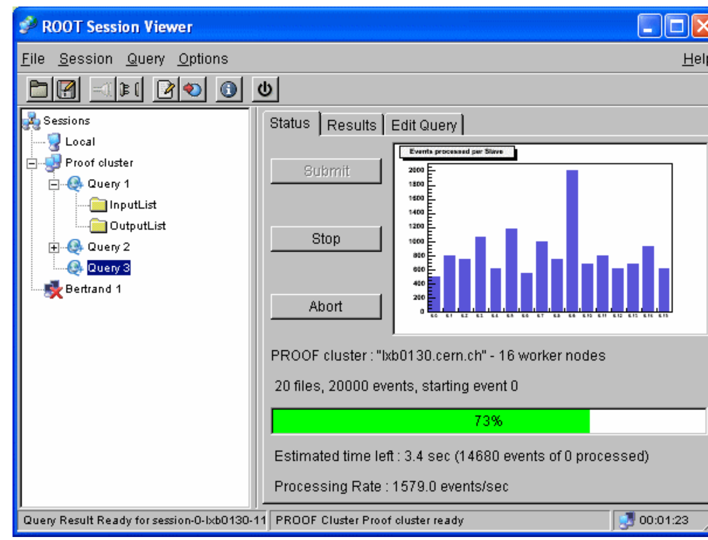
ROOT: Graphics

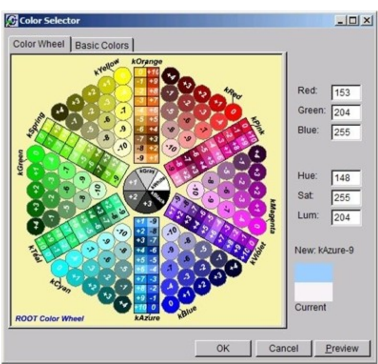


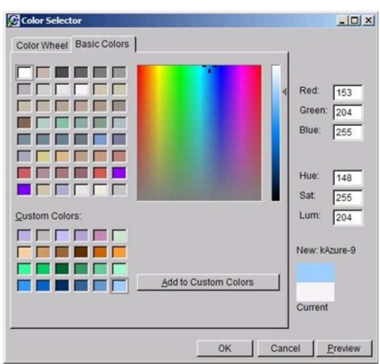
ROOT: Graphical Interfaces

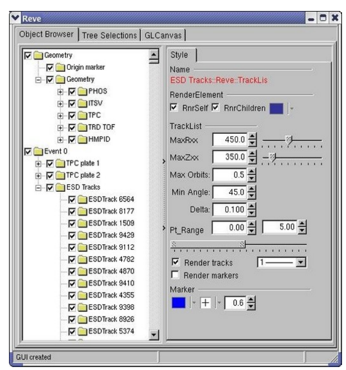




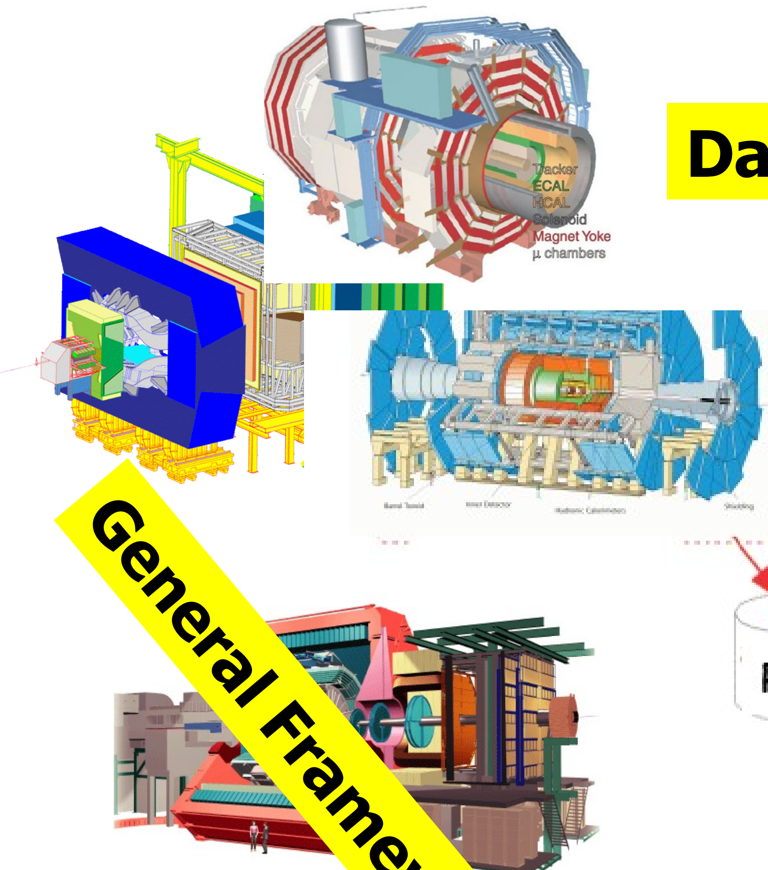






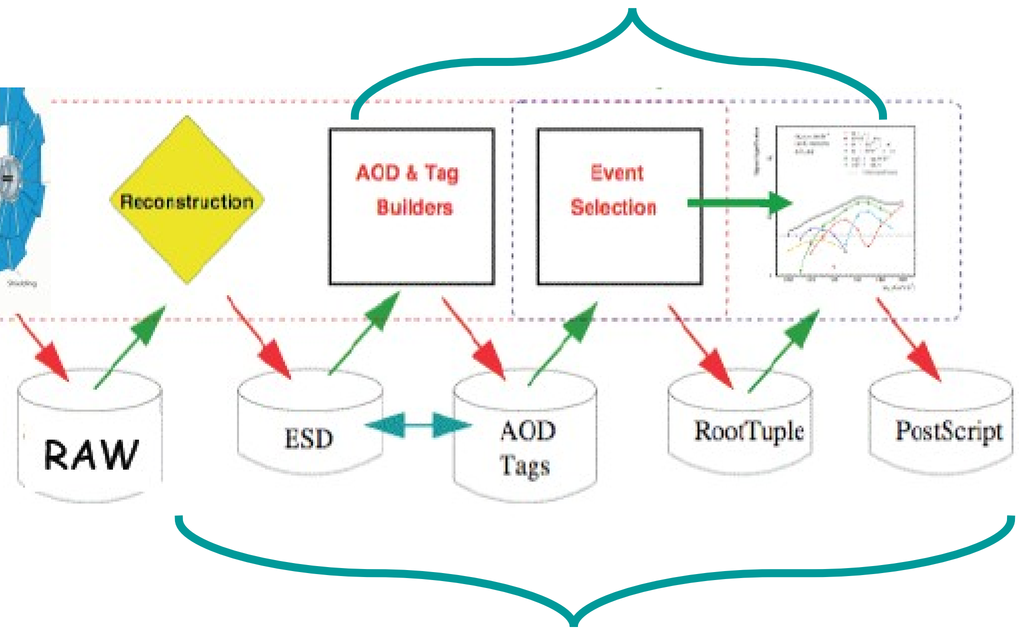


ROOT Application Domains



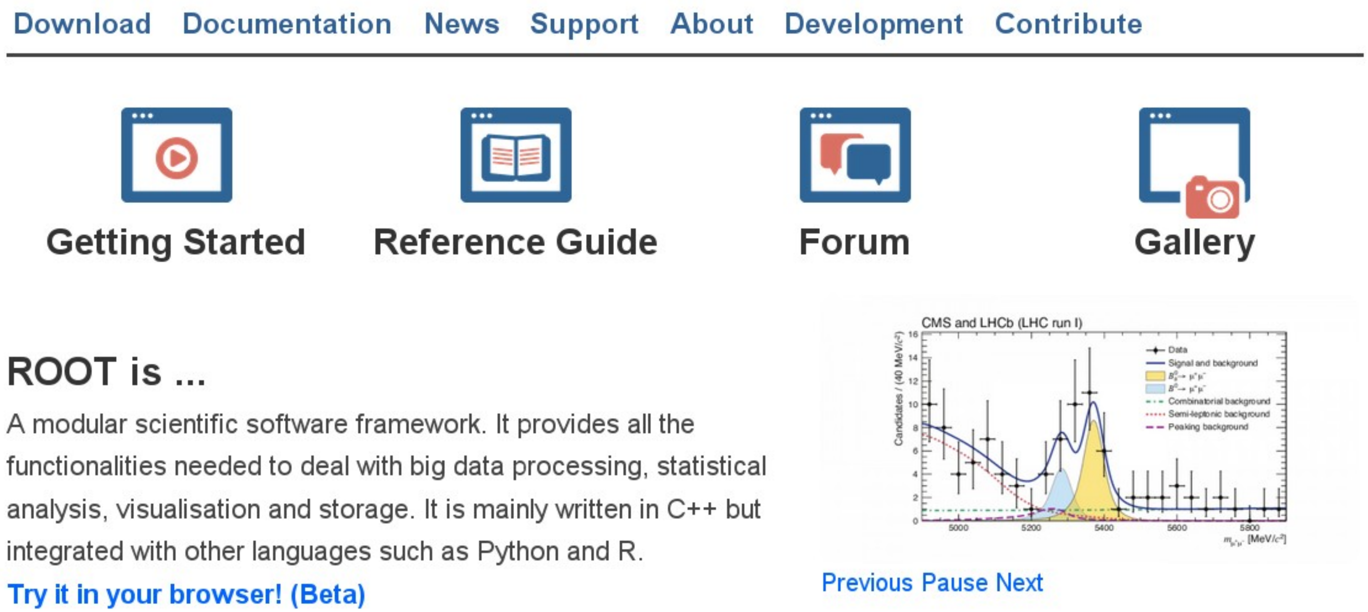
General Framework

Data Analysis & Visualization



Data Storage: Local, Network

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

Installation guide at:
https://root.cern.ch/building-root

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

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/courses
  - https://www.youtube.com/watch?v=s9PTrWOnDy8

ROOT Prompt

- Starting ROOT

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

- The ROOT prompt

```
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 macro1.C
$ root –l –b macro1.C
$ root –l –q macro1.C
```

(batch mode → no graphics)
(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!

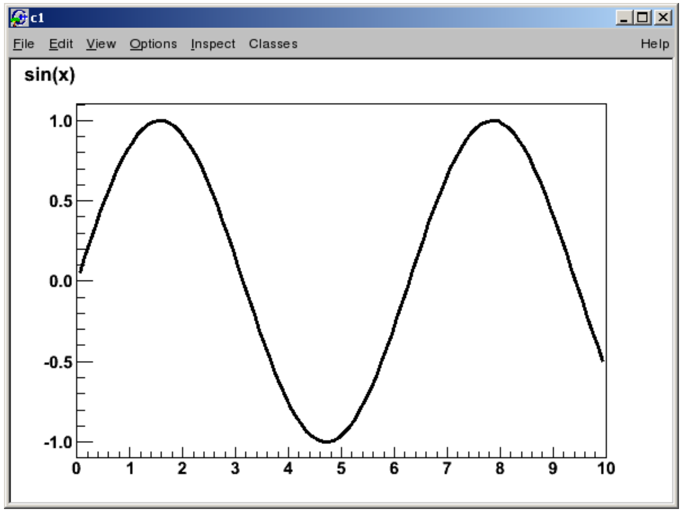
Functions

- 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(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

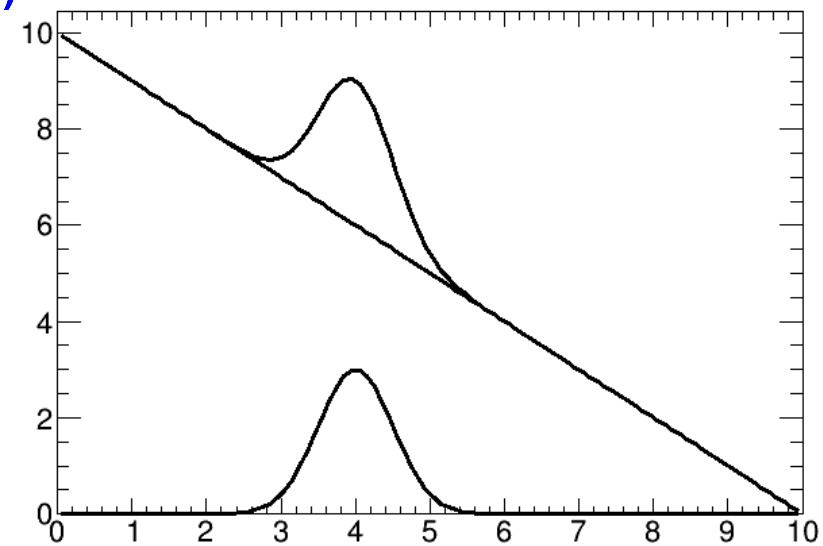
```
root [ ] TF1 f2("func", "cos(x)", 0, 10)
```

- One can point to the other

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

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.

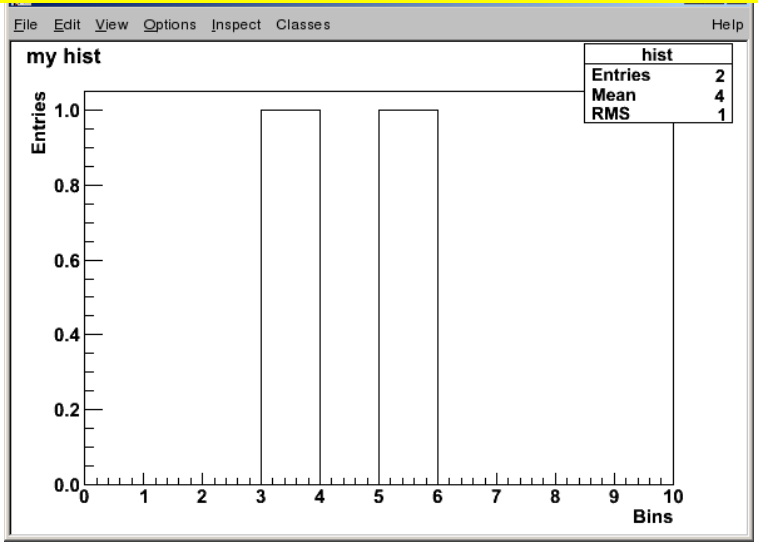
➔ A bin includes the lower limit, but excludes the upper limit

- **Fill the histogram**

  root [ ] h->Fill(3.5);

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

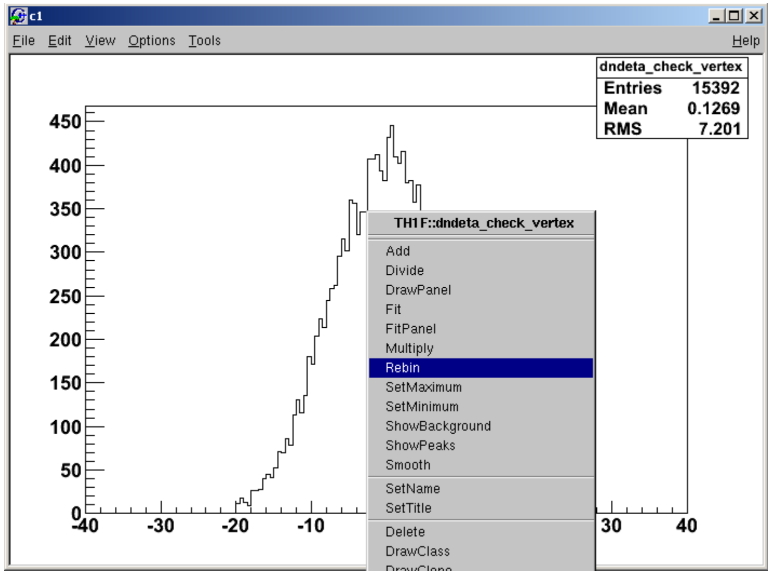
  root [ ] h->Draw();



- **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()
```

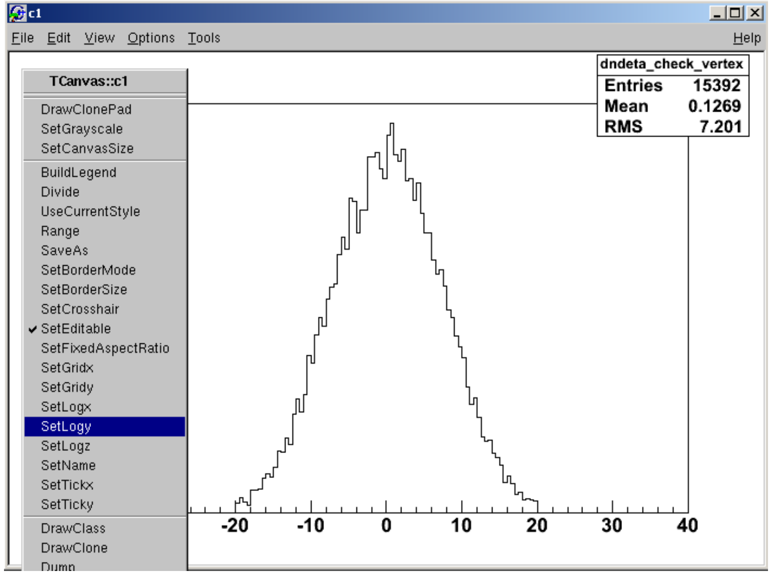


- **Rebinning**

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

- **Change ranges/canvas**
  - with the mouse, very easy!
  - with the context menu
  - command line

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



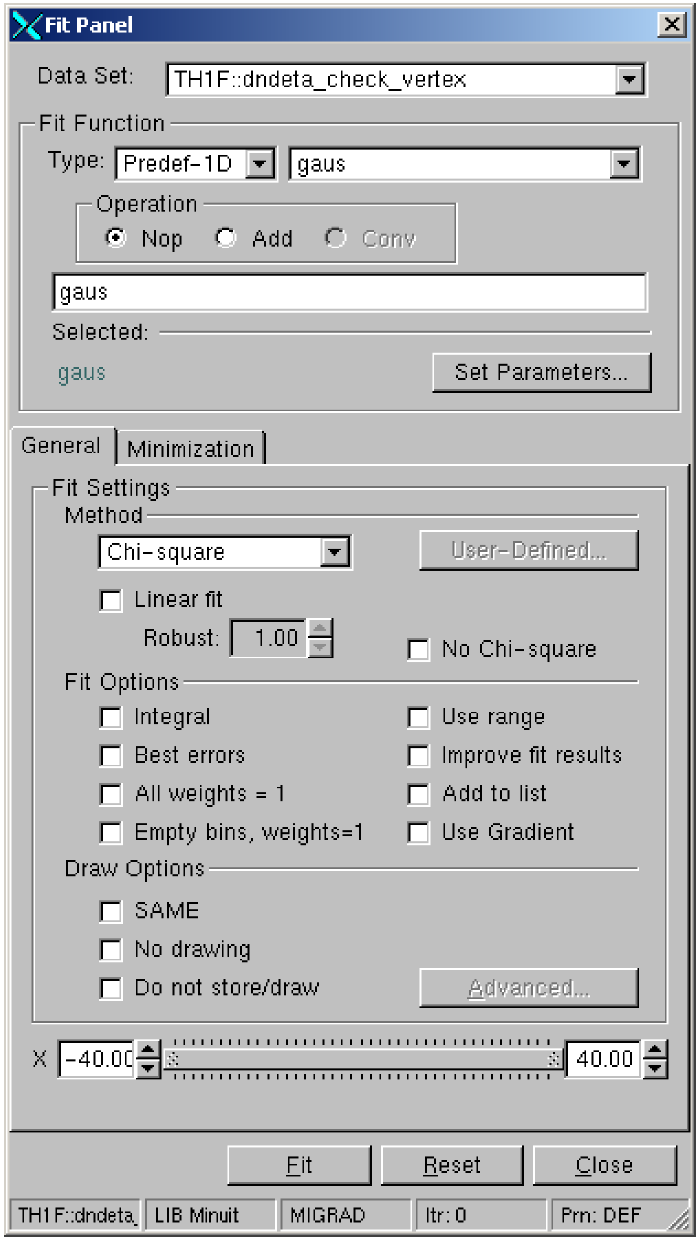
- **Log-view**
  - right-click in the white area at the side of the canvas and select SetLogx (SetLogy)
  - command line

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

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

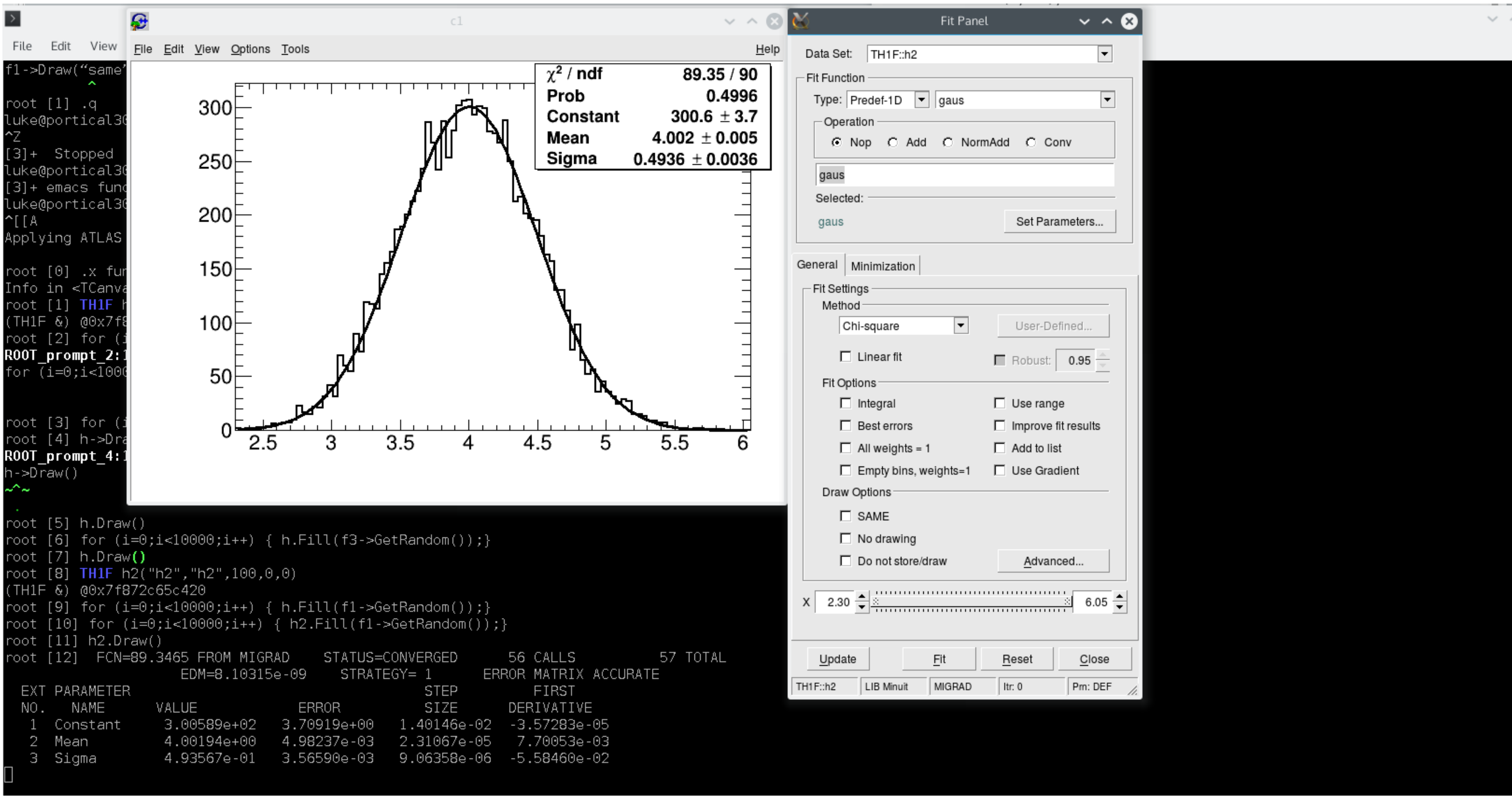
Fitting Histograms

- **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.

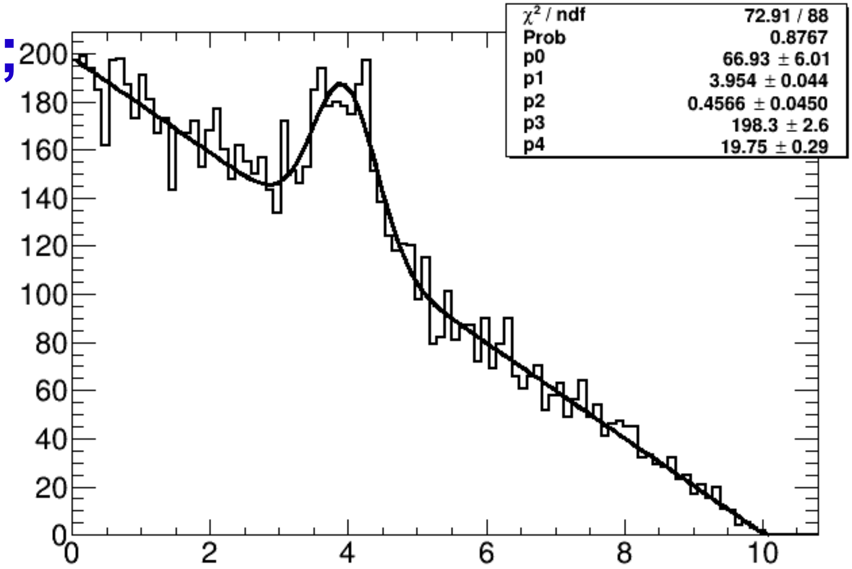
Fitting Histograms



Fitting Histograms (2)

- Now edit function.C → functionfit.C

```
root [ ] TH1F h1("h1","h1",100,0,0);
//auto range
root [ ] for (int i=0;i<10000;i++)
{ h1.Fill(f3->GetRandom());}
root [ ] //create random numbers
according to a function
distribution
root [ ] h1.Draw()
```



- Try to fit 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

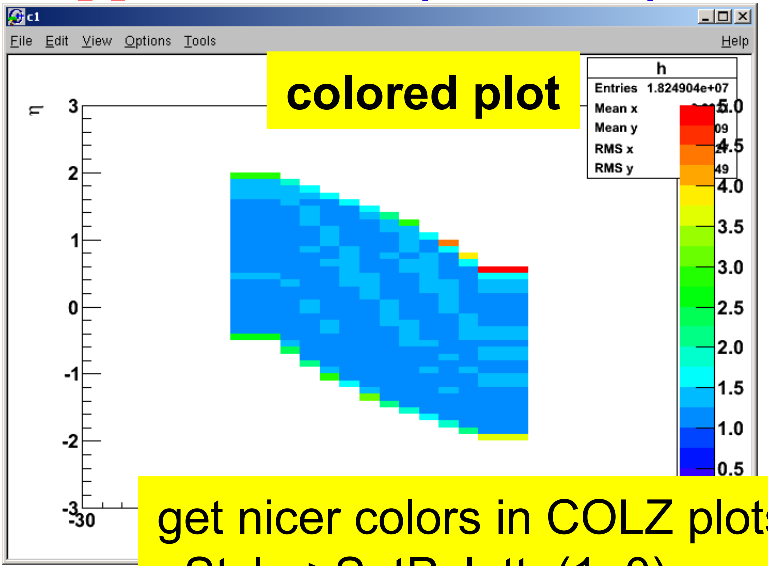
root -l hist2.root

root [ ] TBrowser a

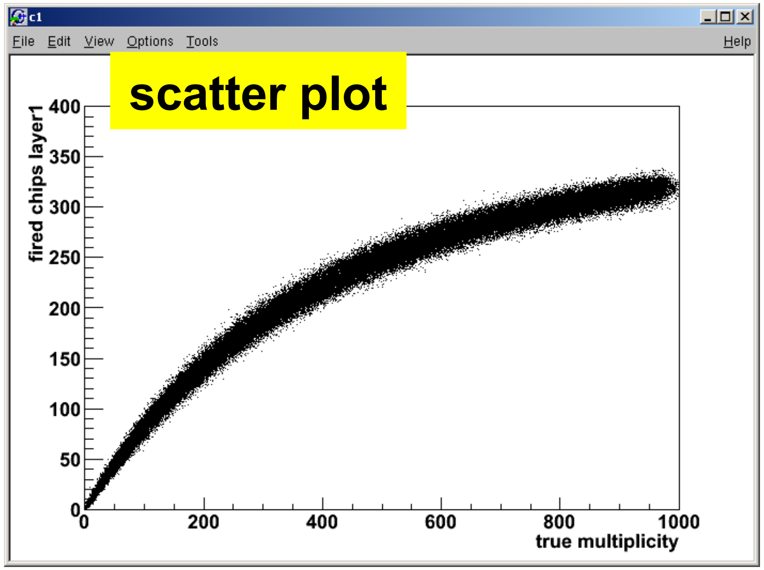
root [ ] h->Draw()

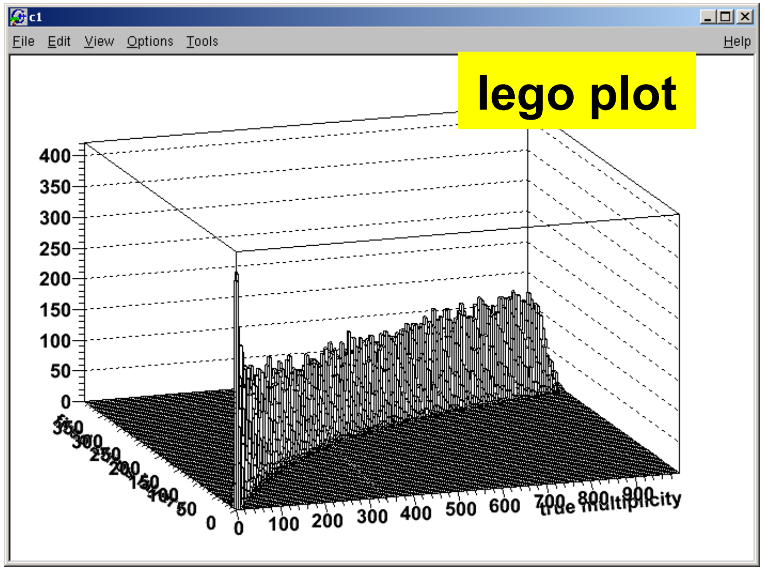
root [ ] h->Draw("LEGO")

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)

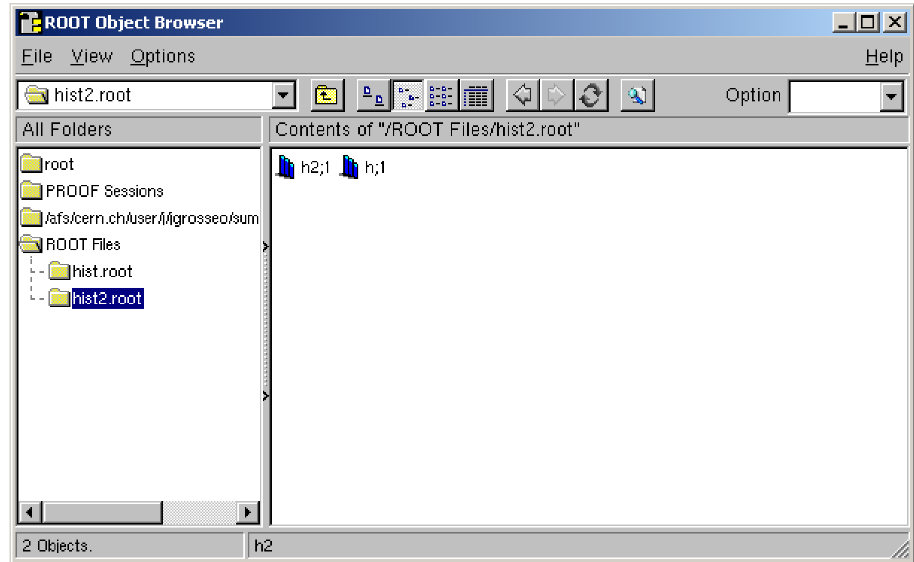
- **Open the file for reading**
  root [ ] file = TFile::Open("file.root")
- **Read the object from the file**
  root [ ] hist->Draw()
  (only works on the command line!)
- **In a macro read the object with**
  TH1F* h = 0;
  file->GetObject("hist", h);
- **What else is in the file?**
  root [ ] .ls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

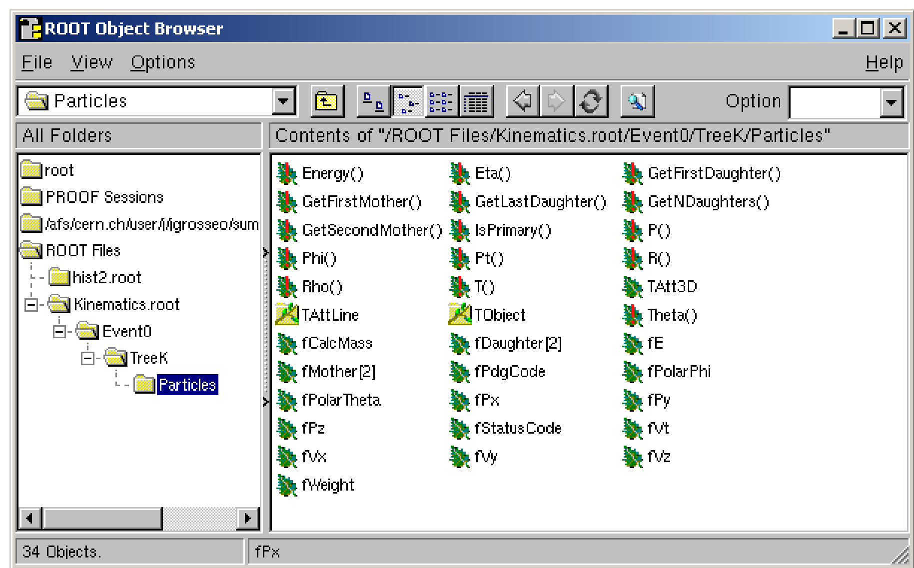
➔ **Object ownership**
After reading an object from a file don't close the file! Otherwise your object is not in memory anymore

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



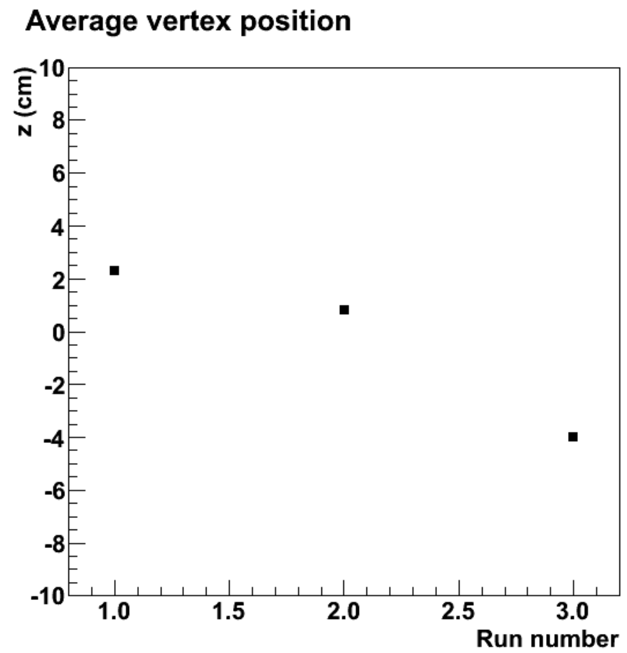


Graphs

- 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 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");
```



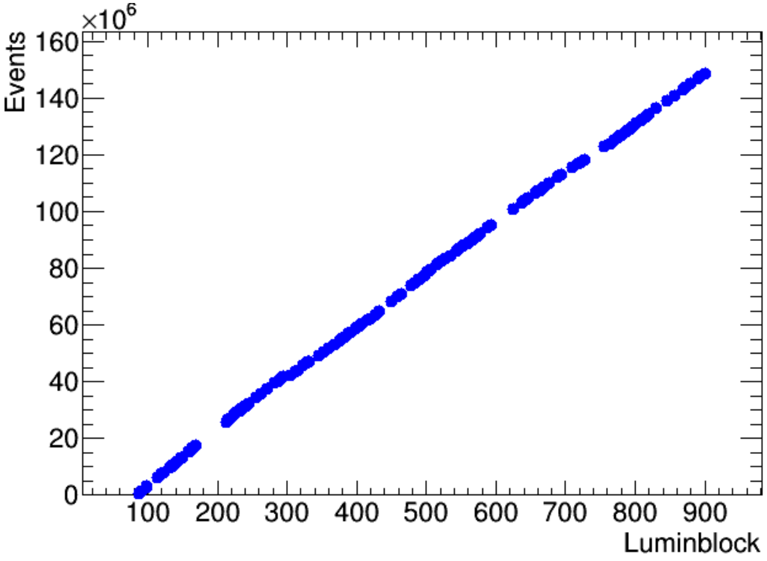
- **try to run .x graph.C**

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");
```



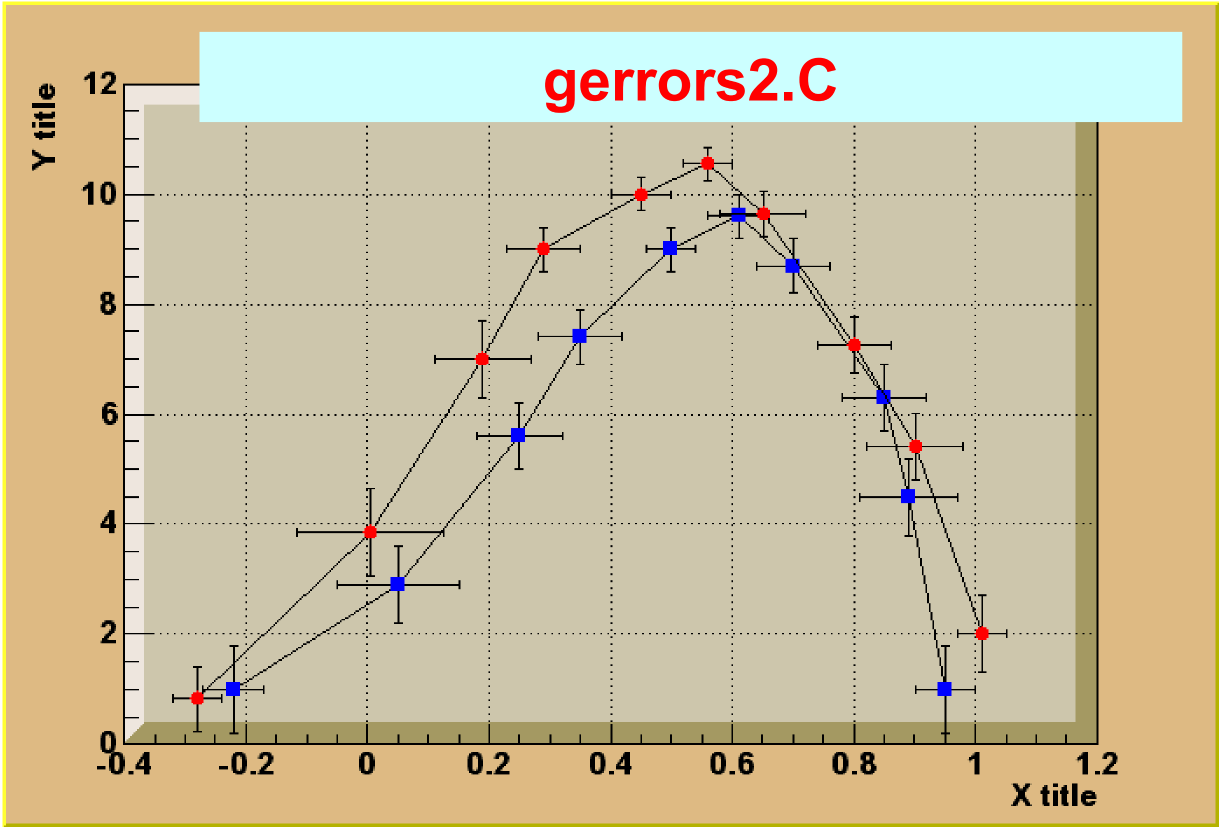
Graphs (3)

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

TGraph(n,x,y)

TCutG(n,x,y)

TMultiGraph

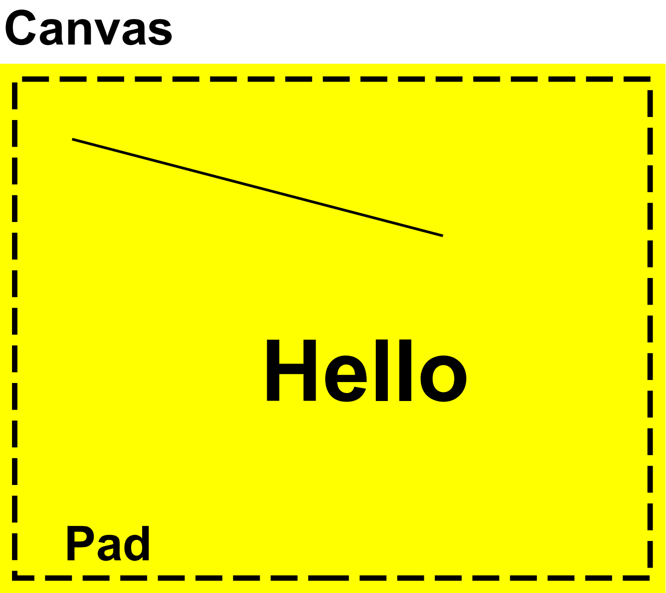


TGraphAsymmErrors(n,x,y,exl,exh,eyl,eyh)

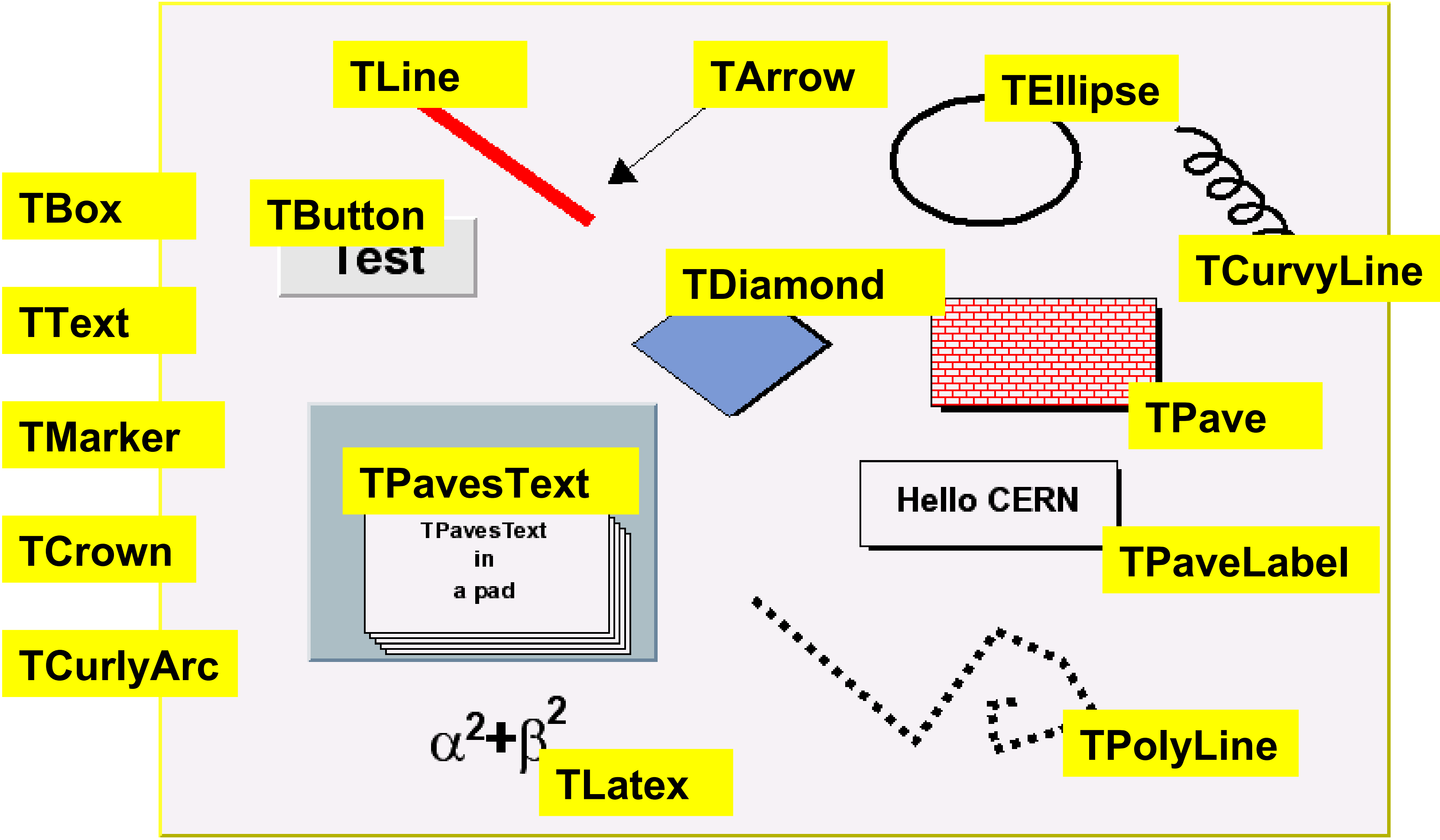
Graphics Objects

- 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

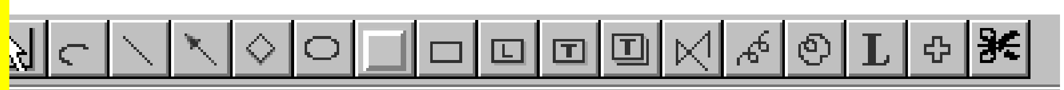
```
root [ ] TLine line(.1,.9,.6,.6)
root [ ] line.Draw()
root [ ] TText text(.5,.2,"Hello")
root [ ] text.Draw()
```



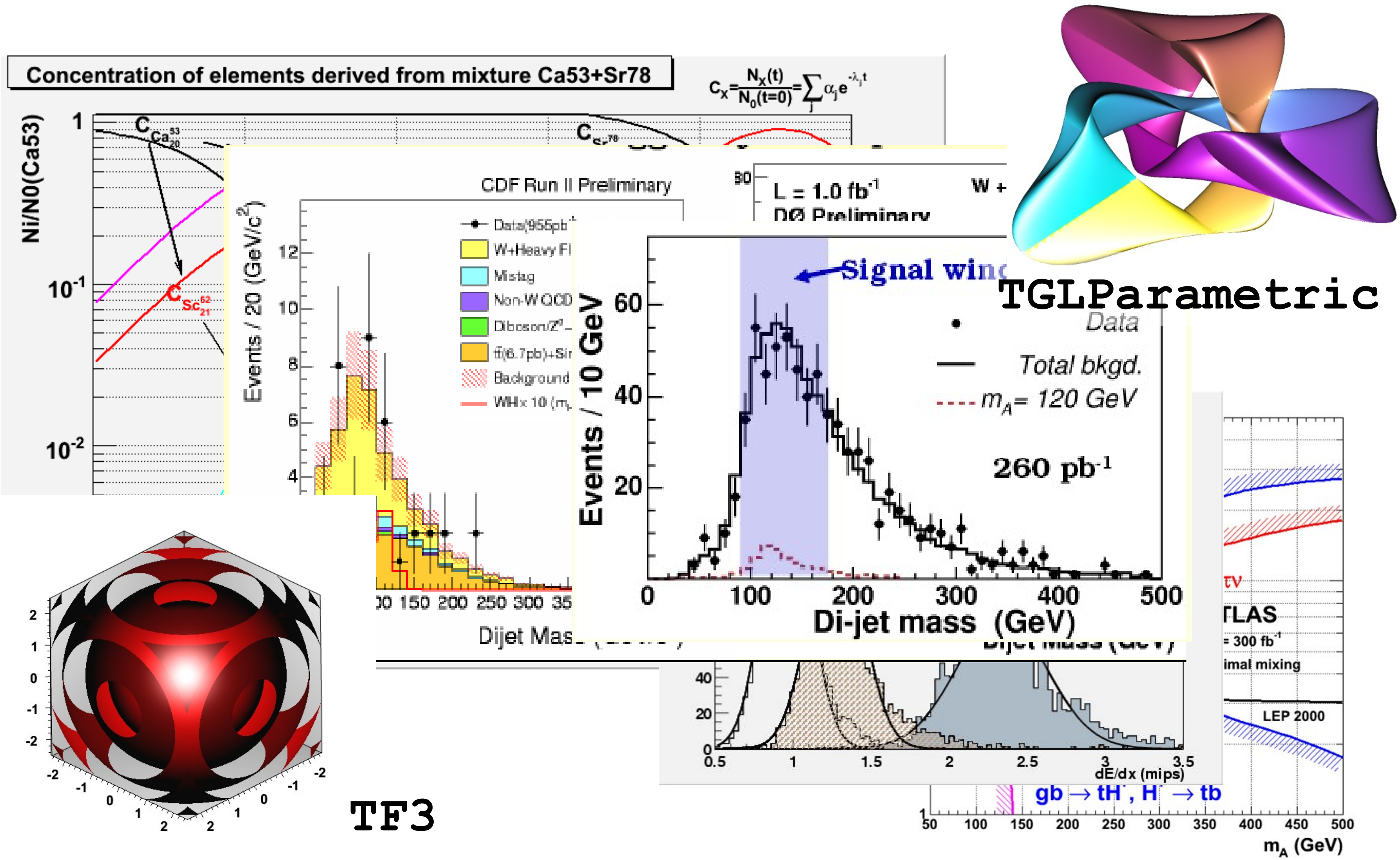
More Graphics Objects



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



Graphics Examples



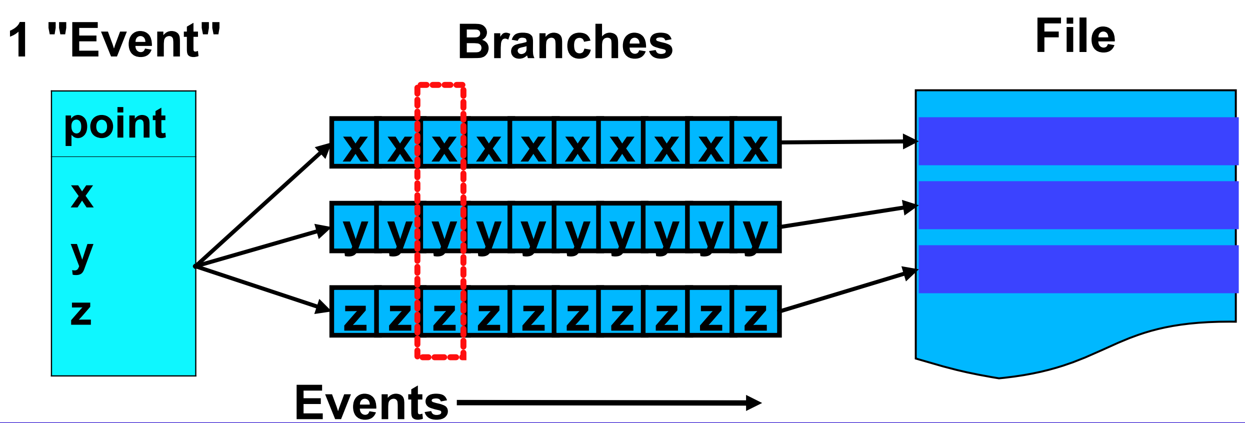
What is a ROOT Tree?

- **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



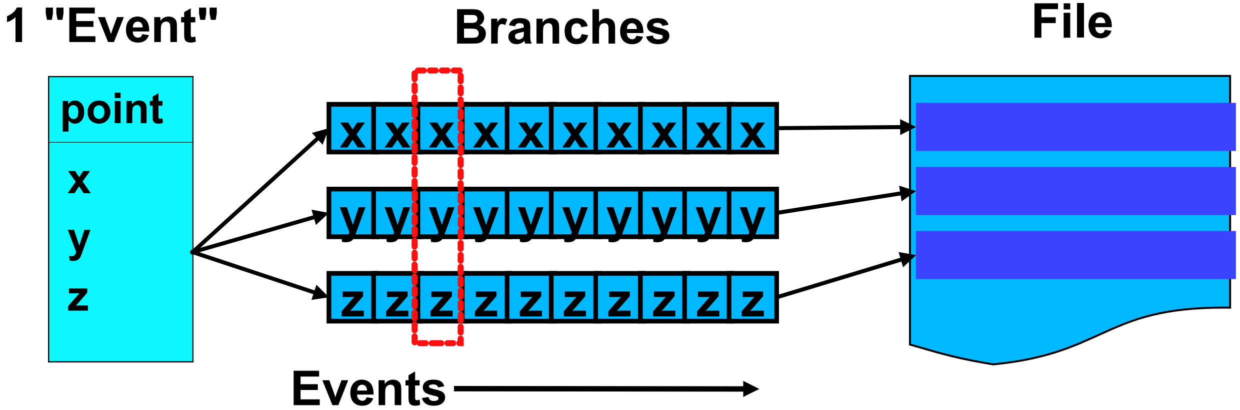
Trees

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

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

Fill the TTree

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

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)**

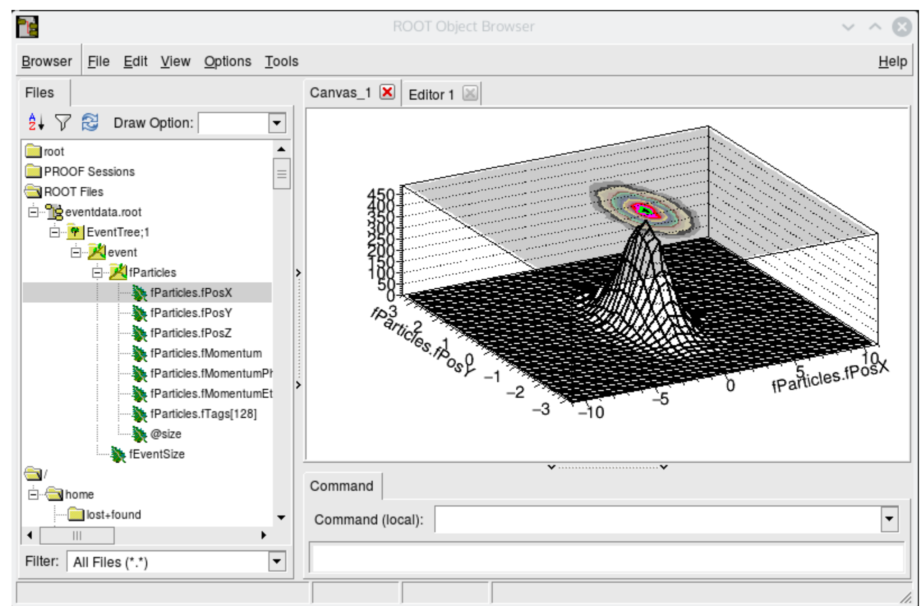
```
$ root eventdata.root
root [ ] tree->Scan();
root [ ] tree->Scan("*");
root [ ] tree->Scan("fParticles.fPosX:fParticles.fPosY:fParticles.fPosZ");
root [ ] tree->Scan("fParticles.fPosX:fParticles.fPosY:fParticles.fPosZ",
    "fParticles.fPosX<0")
```

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



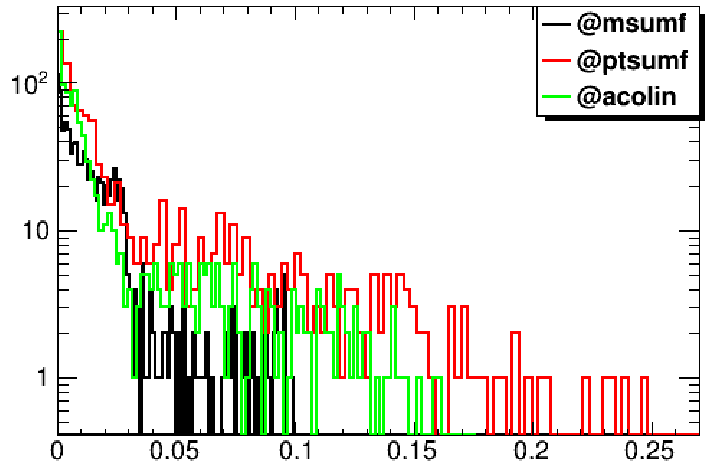
Machine Learning

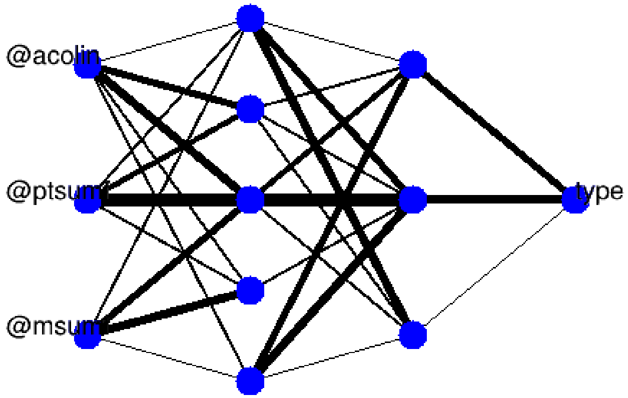
- Example of advanced statistical analysis:
  - Read from a tree the event variables for:
    - “signal” process, e.g. a simulation of a new phenomena you are looking for.
    - simulation of a “background process you want to separate the signal from.
  - Build a Neural Network with these variables,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

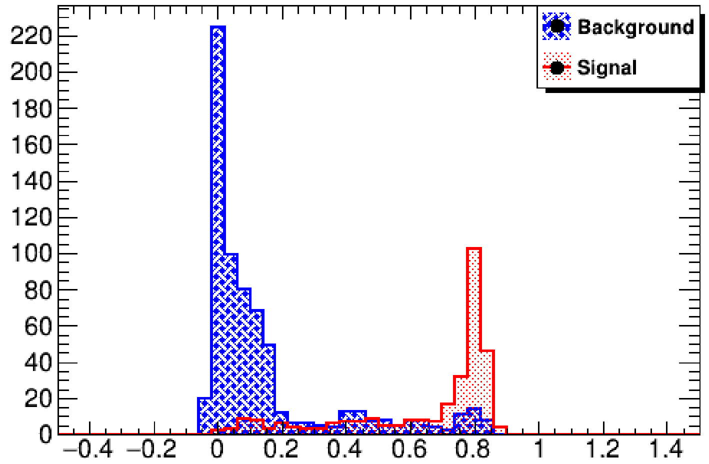
mlpHiggs.root file:

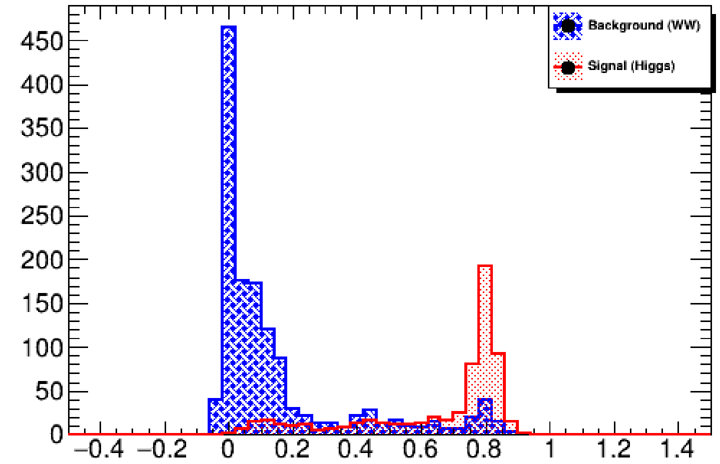
TFile::Open("http://root.cern.ch/files/mlpHiggs.root")

Machine Learning







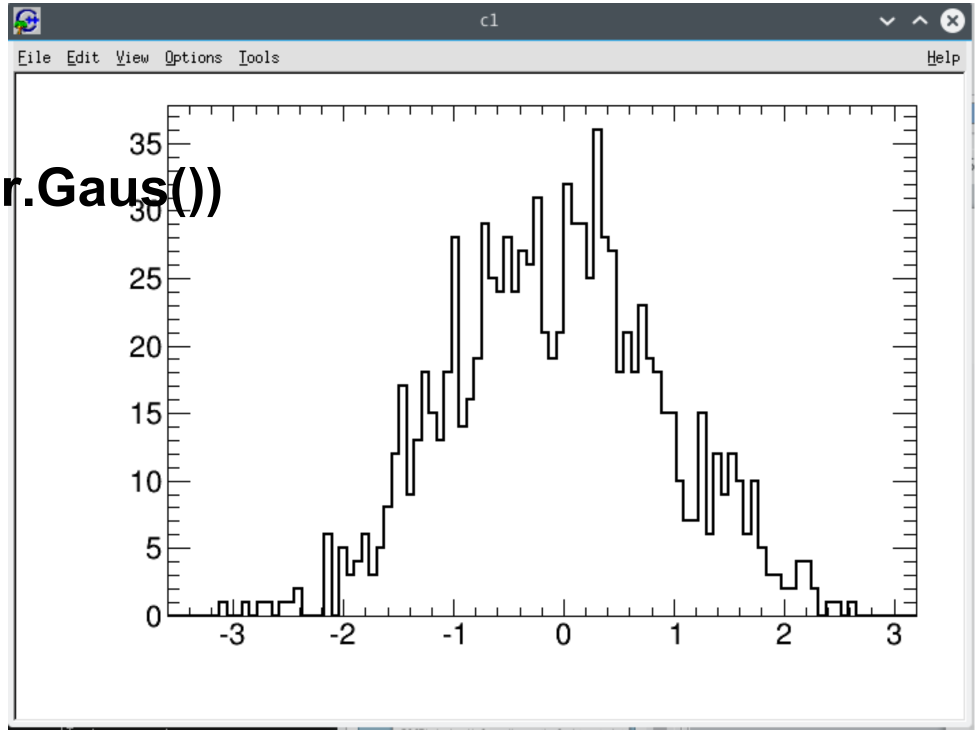


PyRoot

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:

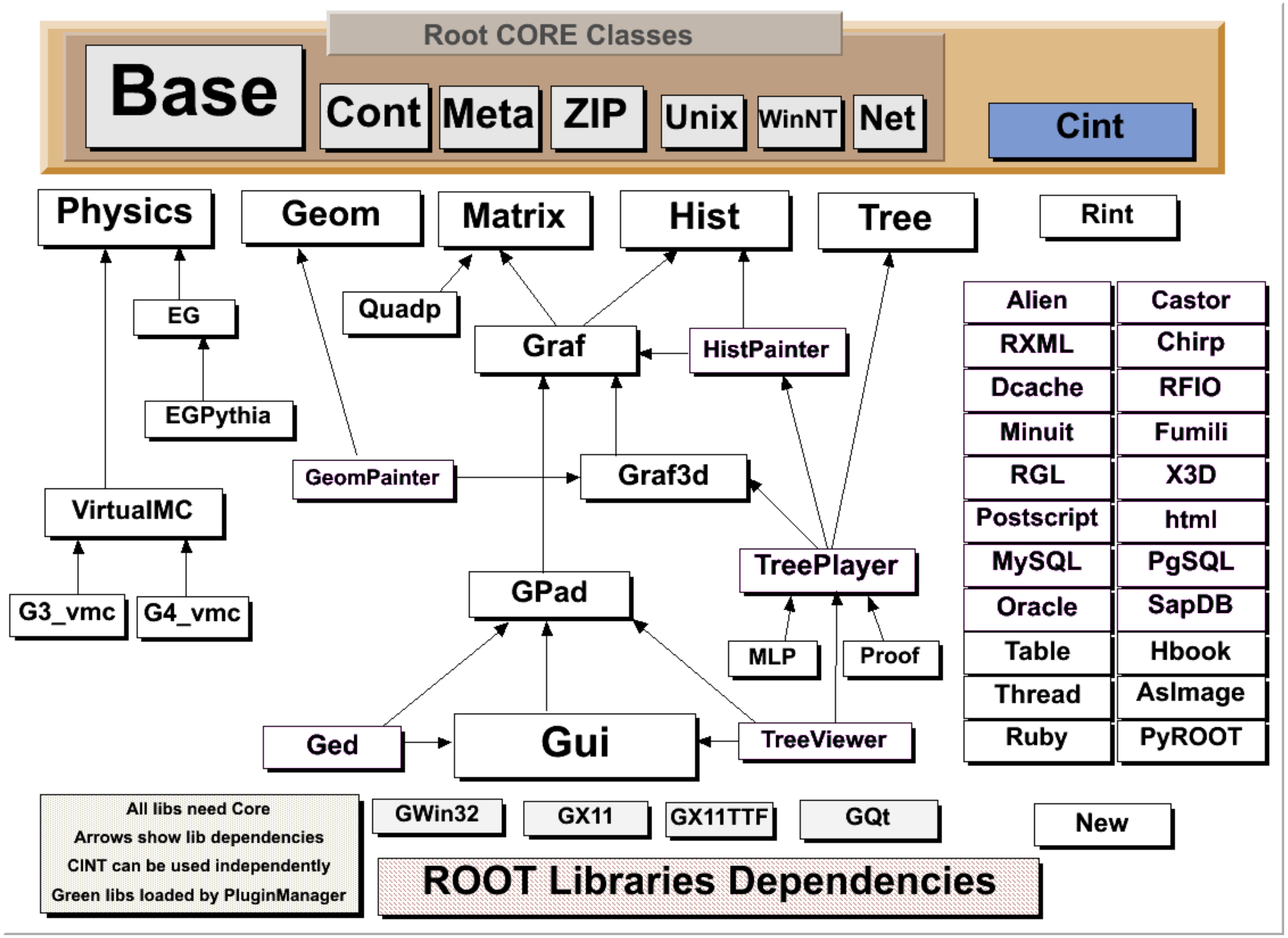
```
In [1]: import ROOT
In [2]: h = ROOT.TH1F("h", "h", 100, 0, 0)
In [3]: h.GetName()
Out[3]: 'h'
In [4]: r= ROOT.TRandom()
In [5]: for i in xrange(0,1000): h.Fill(r.Gaus())
In [6]: h.Draw()
```



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

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