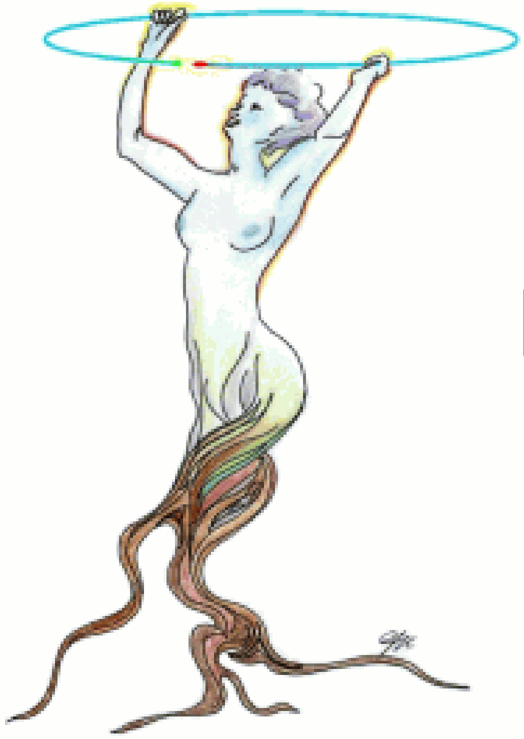
ROOT

An Object-Oriented
Data Analysis Framework



Part 1

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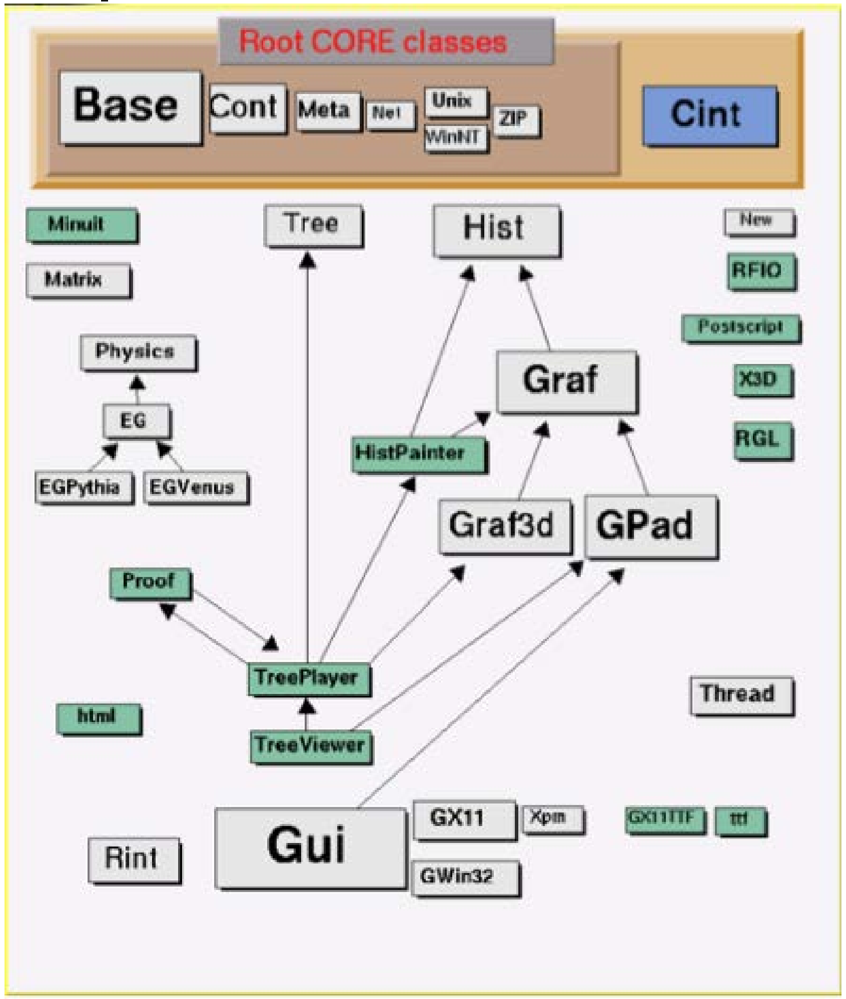
INFN, LNGS and LNS

Thanks to: N. Di Marco, S. Panacek and A. Tramontana

What are the capabilities of ROOT?

- Histograms and fit
- Graphic and scatter plot (2D, 3D)
- **I/O on file**
  - Specialized for histograms and Ntuple (TTrees)
- Support for data analysis
- User interface
  - GUI: Browsers, Panels, Tree Viewer
  - Command line interface: C++ interpeter (CINT)
- Processor for scripts (compiled C++ ⇔ interpreted C++)
- Possibility to use ROOT classes in external programs

ROOT libraries

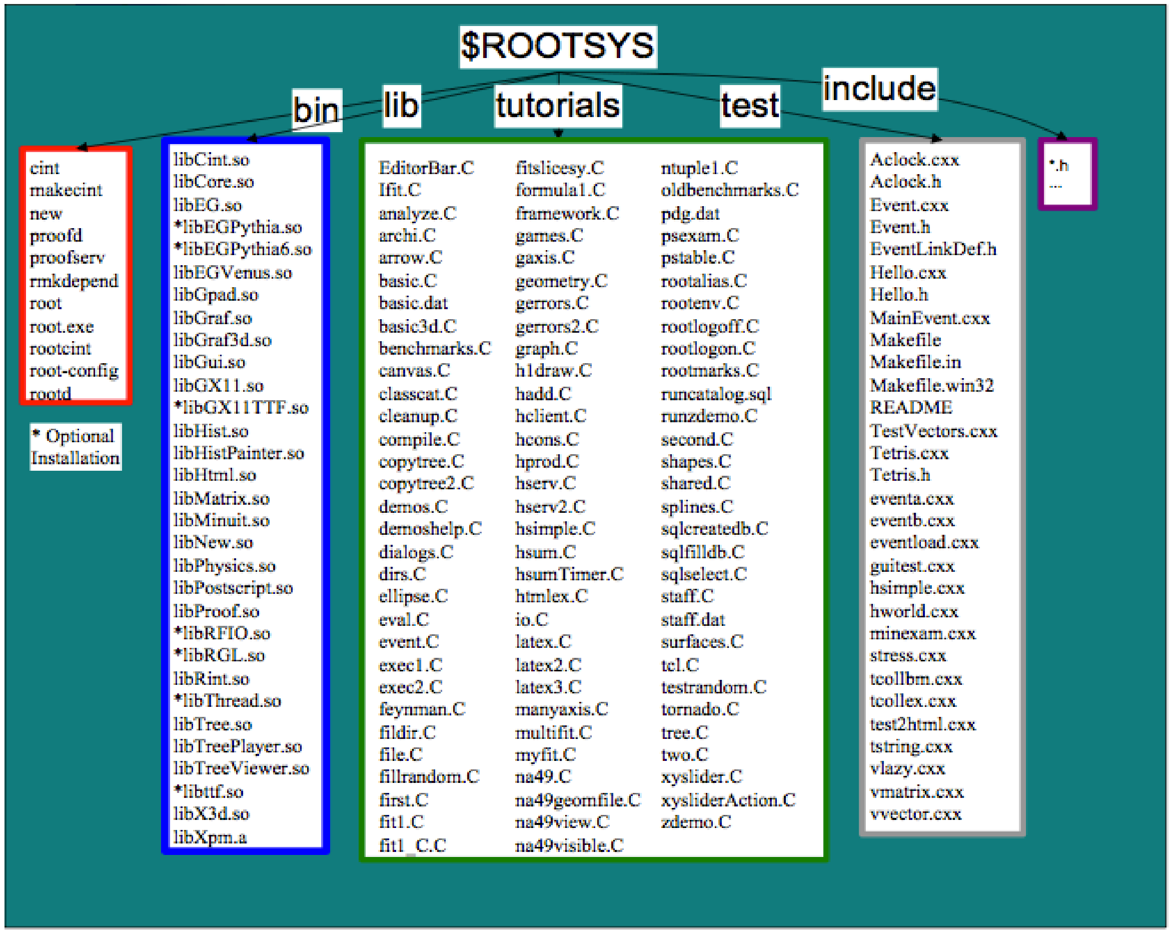


- More than **350 classes**
  - All start with **T**

- Kernel (ROOT Core)
- CINT Interpeter
- Firstly loaded libraries: Hist, Tree, ...
- Libraries loaded if necessary: HistPainter, TreePlayer, ...
- Specific libraries: EG (event generator), Physics, Minuit, ...

The framework organization

- Everything is controlled from the **$ROOTSYS** environment variable
- Directories for *binaries*, *includes* and *compiled libraries*
- Specific tutorials for different user applications



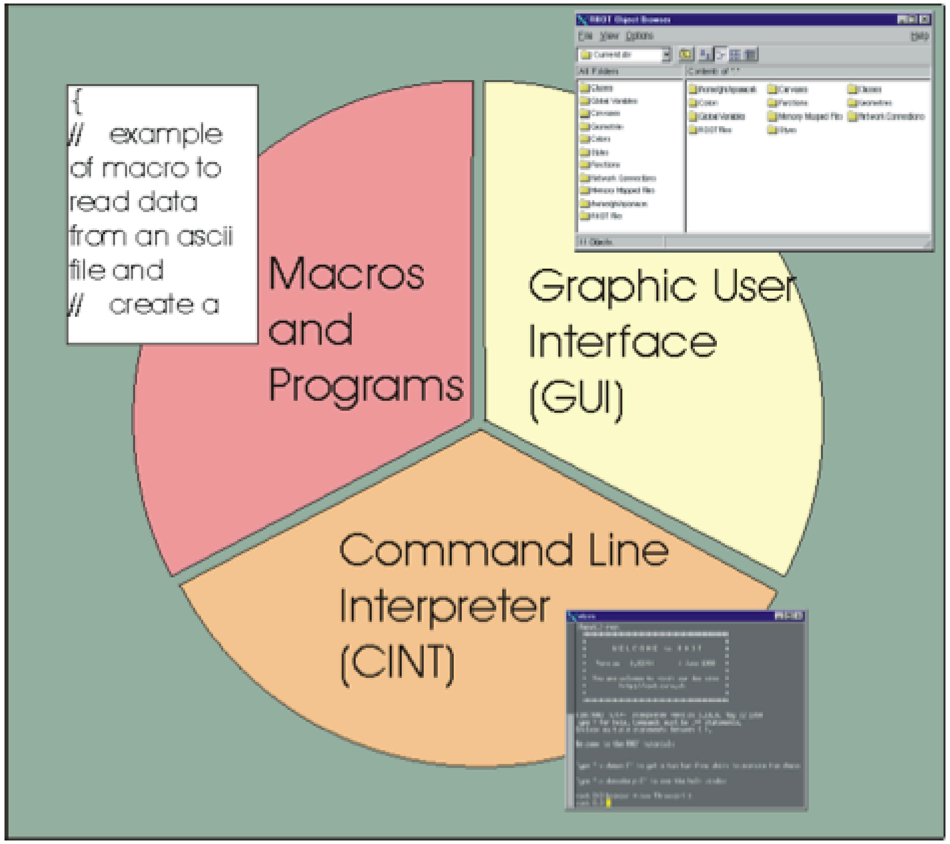
Basic and commands

How can we talk to ROOT?

- Interactive **GUI**
  - buttons, graphic menus, etc.

- ROOT interactive **command line** through CINT (C++ interpreter)

- **Macro**, external **applications** with ROOT classes, libraries (C++ compiler)
  - buttons, graphic menus, etc.


{
// example of macro to read data from an ascii file and
// create a
Macros and Programs
Graphic User Interface (GUI)
Command Line Interpreter (CINT)

What can we do with GUI?

- ROOT files **search** and **opening**
- **Histogram** drawing
- **Contextual menus** with 3 mouse clicks
- **Draw** panel:
  - Parameters choice, colors, etc.
- **Fit** panel:
  - Parameters choice, limits, etc.
- Add **text**, **legend** or other objects
- Window **separation** (**TCanvas**)
  - Selection of lin/log scales

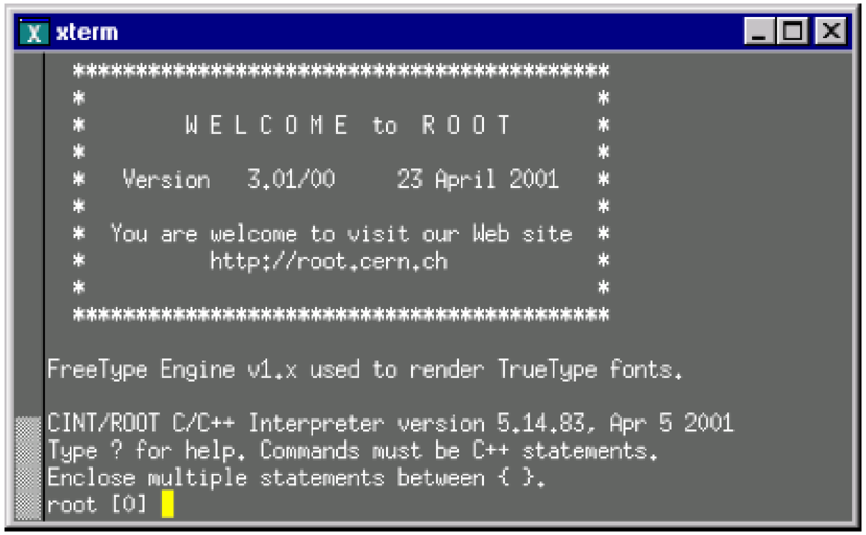
ROOT: command line and GUI

Enter in ROOT

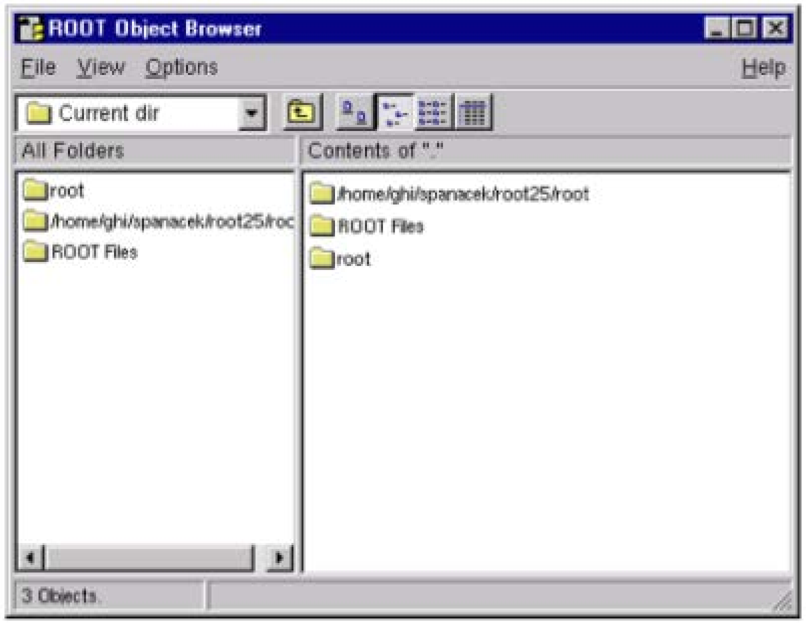
```
> root
```

Exit from ROOT

```
root[0] .q
```



```
xterm
  *******************************************
  *                                         *
  *        W E L C O M E  to  R O O T       *
  *                                         *
  *   Version   3.01/00     23 April 2001   *
  *                                         *
  *  You are welcome to visit our Web site  *
  *          http://root.cern.ch            *
  *                                         *
  *******************************************

FreeType Engine v1.x used to render TrueType fonts.

CINT/ROOT C/C++ Interpreter version 5.14.83, Apr 5 2001
Type ? for help. Commands must be C++ statements.
Enclose multiple statements between { }.
root [0]
```



ROOT Object Browser

File View Options Help

Current dir

All Folders	Contents of "."
root	/home/ghi/spanacek/root25/root
/home/ghi/spanacek/root25/roc	ROOT Files
ROOT Files	root

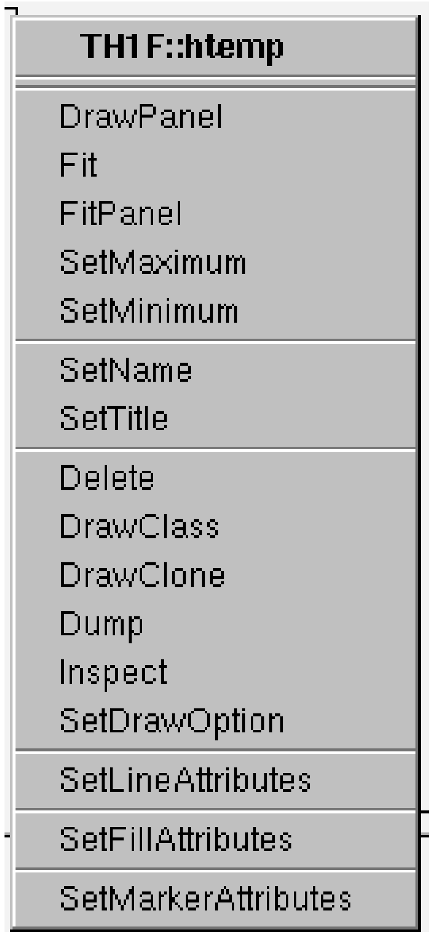
3 Objects.

Browser opening

```
TBrowser b;
```

GUI: basic navigation by clicking

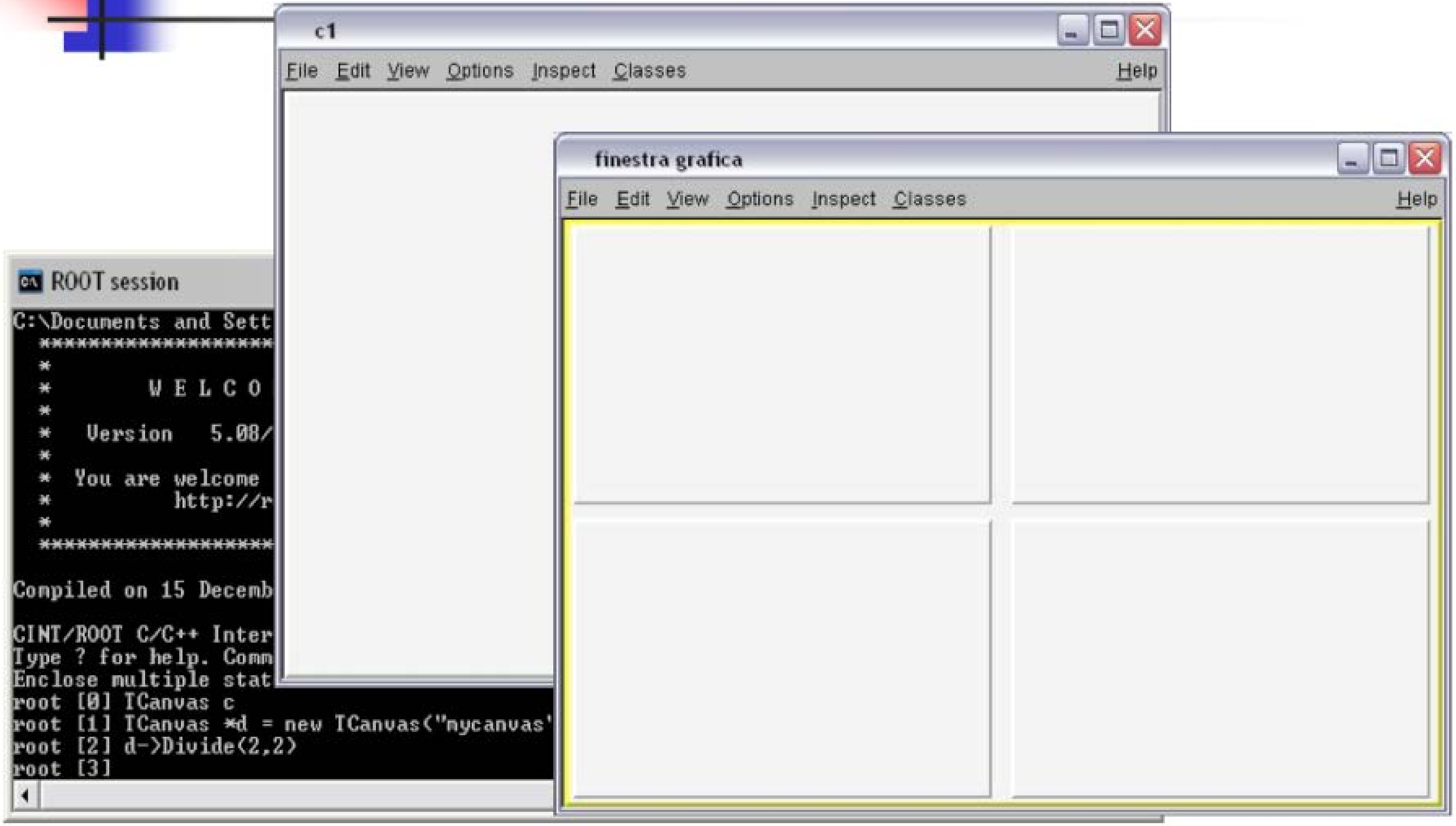
- Left Click
  - select the object
  - drag the object
  - resize the object
- Right Click
  - context menu
  - class::name
  - methods
- Middle Click
  - activate canvas
  - Freezes event status bar



GUI / interactive / macros: when and what

- GUI
  - quick tasks using "standard" features
  - fine-tuning of plots, adjustments, labels, etc.
- Command line
  - quick "real-life" analysis, check outputs
  - Retrieve numbers (e.g. counts in a histogram)
- Macro
  - All real-life analysis tasks will required dedicated (compiled) macros
  - Full control and flexibility for input and output

Basic elements of ROOT


c1
File Edit View Options Inspect Classes Help
finestra grafica
File Edit View Options Inspect Classes Help
ROOT session

```
C:\Documents and Sett
  *******************
  *
  *       W E L C O
  *
  *   Version   5.08/
  *
  *  You are welcome
  *          http://r
  *
  *******************

Compiled on 15 Decemb

CINT/ROOT C/C++ Inter
Type ? for help. Comm
Enclose multiple stat
root [0] TCanvas c
root [1] TCanvas *d = new TCanvas("mycanvas'
root [2] d->Divide(2,2)
root [3]
```

Three types of command

1. **CINT** commands start with “.”

```
root[0] .?
```

- List of all CINT commands

```
root[1] .x  [filename]
```

- Loads [filename] and runs the function [filename] (same name of the file)

```
root[2] .L  [filename]
```

- Load [filename]

2. **Shell** commands start with “.!”, ex.

```
root[3] .!  ls
```

Three types of command

3. (Kind of) **C++-like syntax**

```
root [0] TBrowser *b = new TBrowser()
```
or
```
root [0] TBrowser *b = new TBrowser();
```

“**;**” is **optional**:
If it is non given, ROOT shows the return value (if any) of the command :

```
root [0] 23+5   // shows the return value
(int)28
root [1] 23+5;  // no return value
root [2]
```

Getting help from the command line

- Start writing and **press TAB** for auto-completion
- Classes
  - `[] TCa      [TAB]`

    Completed to **`TCanvas`**
- List of methods
  - `[] TH1D::GetMe [TAB]`
    - `GetMean()`
    - `GetMeanError()`
- Parameters and return types of methods
  - `[] TH1D* h1 = new TH1D(   [TAB]`
    - `TH1D TH1D(const char* name, const char* title, Int_t nbinsx, Double_t xlow, Double_t xup)`
    - `TH1D TH1D(const char* name, const char* title, Int_t nbinsx, const Float_t* xbins)`
    - …

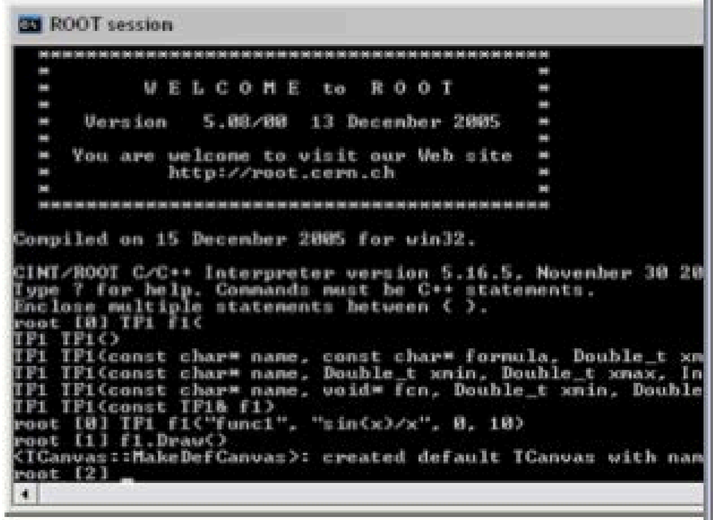
Functions and histograms

1-dim functions (class TF1)

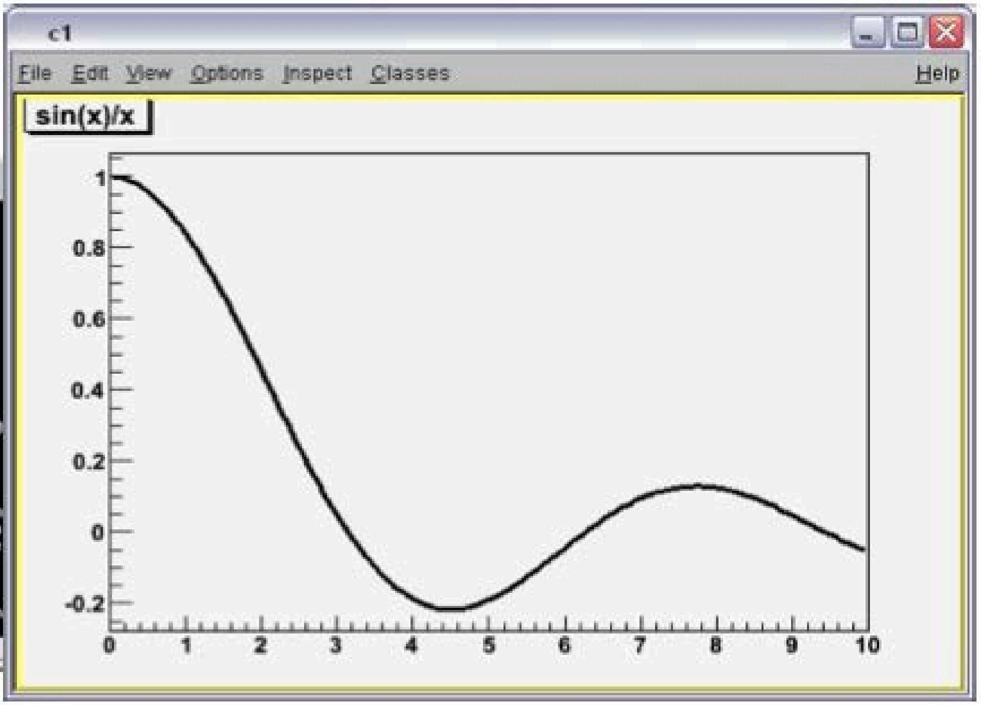
- **TF1** -> 1D functions *f(x)*
  - Each function is identified by a name (string)
  - There are some predefined functions
    - ‘gaus’, ‘expo’,’pol0’, ..., ‘polN’
    - Already known by the command line
- **Custom user functions** can be defined
  - Starting from existing functions, ex. ‘gaus+expo’
  - Writing explicit formulas in text format, ex. ‘sin(x)/x’
  - For more complicated funcions, writing a function *f(x)* from a given ***x*** value (and free parameters)
- Classes TF2 and TF3 for 2- and 3-dim functions

Define and plot a function

```
                name     formula           range
[ ]TF1 f1("func1","sin(x)/x",0,10)
[ ]f1.Draw()
```

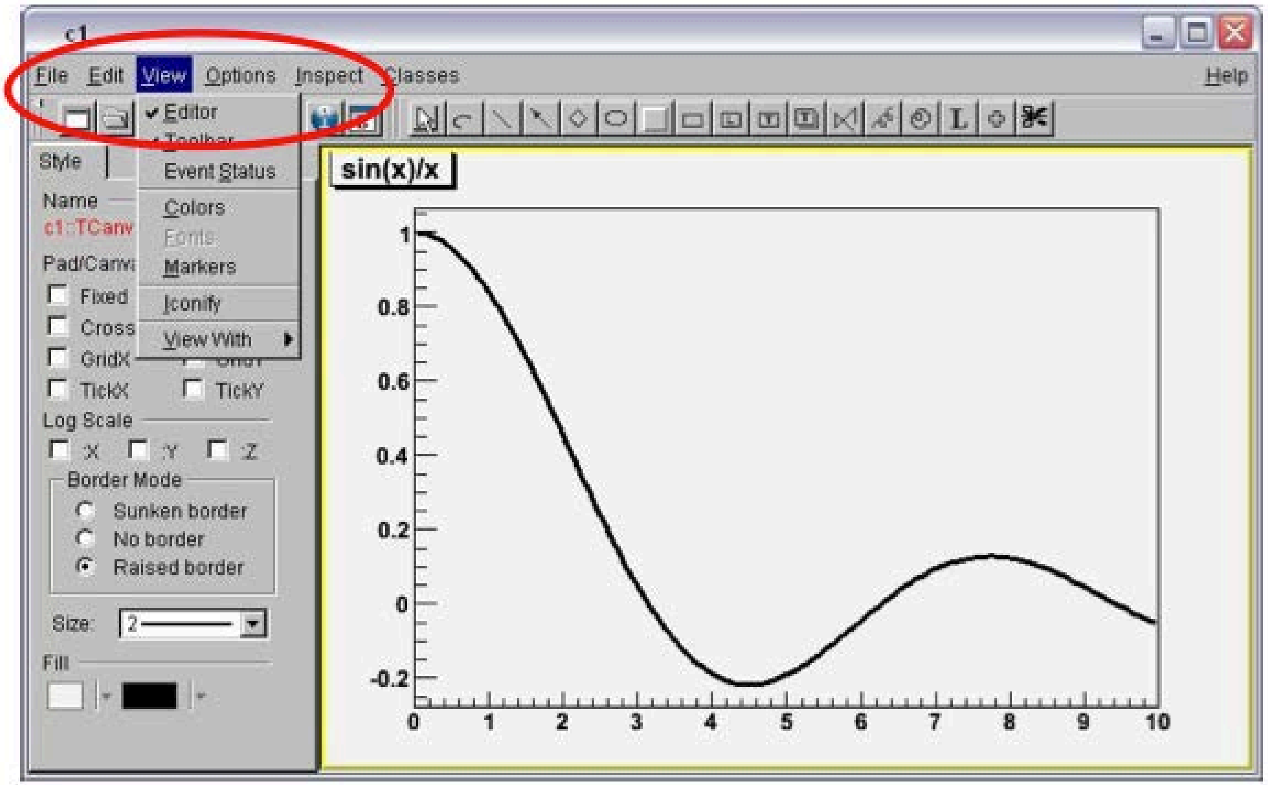


```
  ******************************************
  *                                        *
  *        W E L C O M E  to  R O O T      *
  *                                        *
  *   Version   5.08/00  13 December 2005  *
  *                                        *
  *  You are welcome to visit our Web site *
  *          http://root.cern.ch           *
  *                                        *
  ******************************************

Compiled on 15 December 2005 for win32.

CINT/ROOT C/C++ Interpreter version 5.16.5, November 30 20
Type ? for help. Commands must be C++ statements.
Enclose multiple statements between { }.
root [0] TF1 f1(
TF1 TF1()
TF1 TF1(const char* name, const char* formula, Double_t xm
TF1 TF1(const char* name, Double_t xmin, Double_t xmax, In
TF1 TF1(const char* name, void* fcn, Double_t xmin, Double
TF1 TF1(const TF1& f1)
root [0] TF1 f1("func1", "sin(x)/x", 0, 10)
root [1] f1.Draw()
<TCanvas::MakeDefCanvas>: created default TCanvas with nam
root [2]
```



Adjust an existing plot

- Interactive selection of:
  - Axis scales, titles and labels
  - Colors
  - Line width
  - Style
  - Weight
  - Log scale
  - Grids



Border Mode: Sunken border / No border / [✓ Raised border]

Size: 2

Histograms

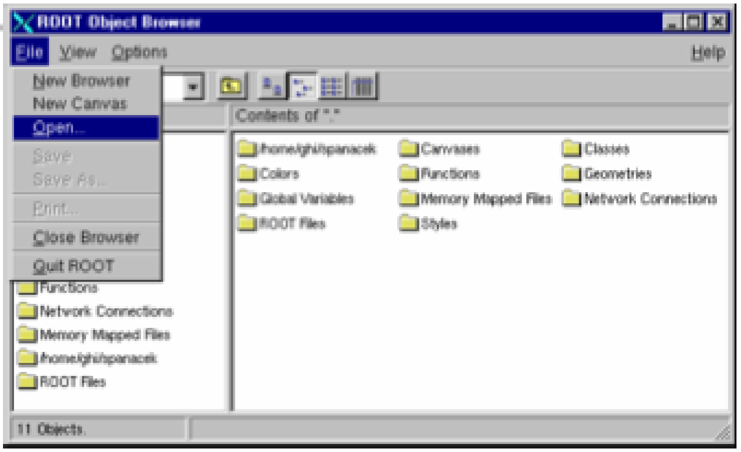
- **TH1D, TH1F, TH1I** -> 1D histograms in ROOT
  - D = double, F = float, I = int
  - Parameters are: name (string), title (string), number of bins and range
- TH2* and TH3* for multi-dimension histograms
  - Support advanced plotting: colour codes, LEGO plots, contour plots, etc
- All histogram classes derive from the **same base interface**, so they have the same basic commands
- Histogram handling supported:
  - operations between histograms (sum, multiplication)
  - operation between histogram and function
  - scaling, rebinning, ...

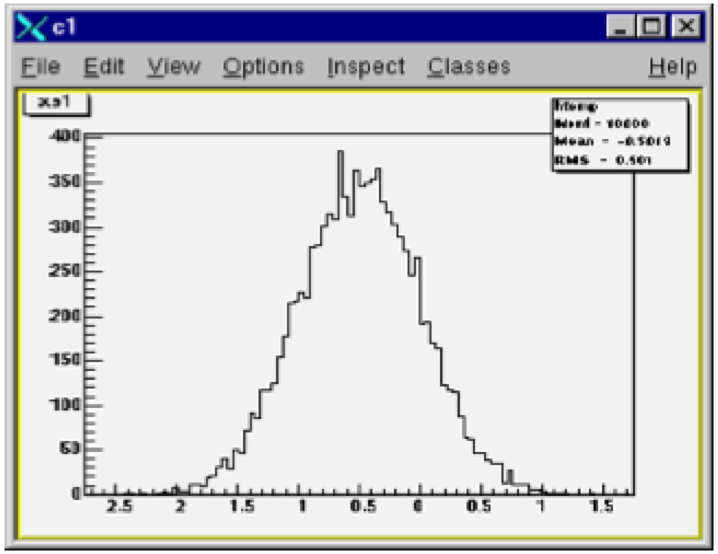
Plot of an histogram

Open a ROOT file with a **Browser**, search of the histrogram from a file

The **double click** on the histogram opens automatically the canvas

Use **`Draw()`** from the command line

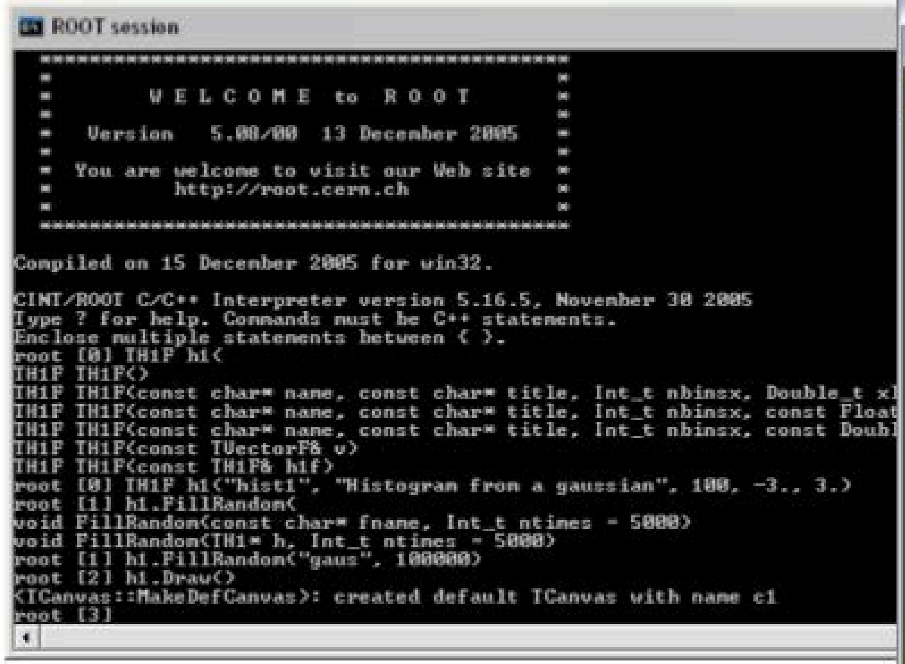




Creation of an histogram

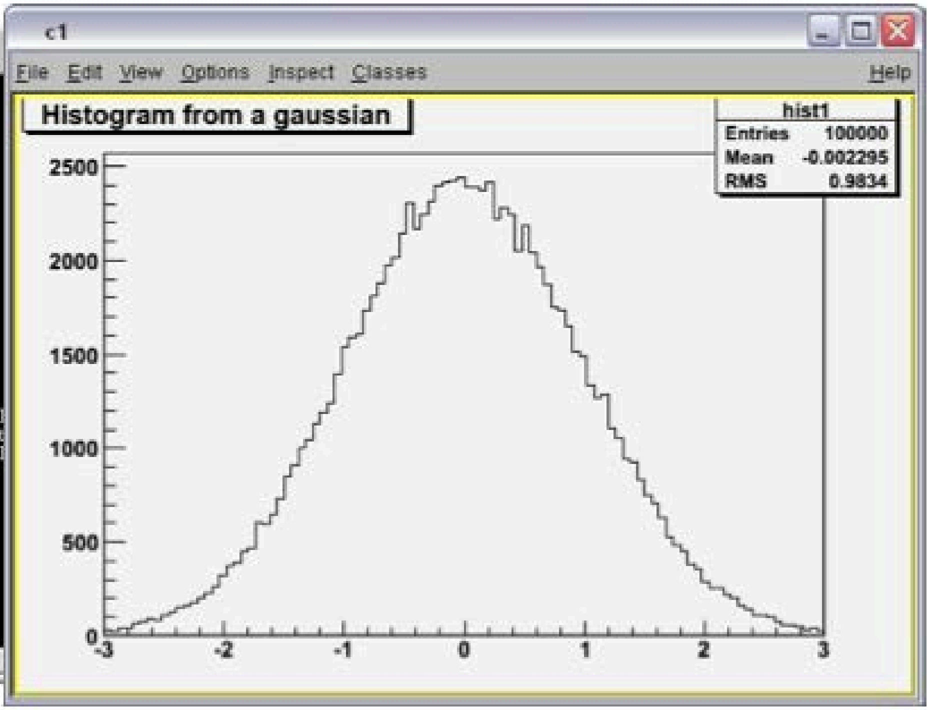
name　　title　　bins　range

[ ] TH1D h1(“hist”,”Histogram from a gaussian”,100,-3,3);
[ ] h1.FillRandom(“gaus”,100000); ← Fill with 10^5 values from “gaus”
[ ] h1.Draw()



ROOT session

```
  *******************************************
  *                                         *
  *        W E L C O M E  to  R O O T       *
  *                                         *
  *   Version   5.08/00  13 December 2005   *
  *                                         *
  *  You are welcome to visit our Web site  *
  *          http://root.cern.ch            *
  *                                         *
  *******************************************

Compiled on 15 December 2005 for win32.

CINT/ROOT C/C++ Interpreter version 5.16.5, November 30 2005
Type ? for help. Commands must be C++ statements.
Enclose multiple statements between { }.
root [0] TH1F h1(
TH1F TH1F()
TH1F TH1F(const char* name, const char* title, Int_t nbinsx, Double_t xl
TH1F TH1F(const char* name, const char* title, Int_t nbinsx, const Float
TH1F TH1F(const char* name, const char* title, Int_t nbinsx, const Doubl
TH1F TH1F(const TVectorF& v)
TH1F TH1F(const TH1F& h1f)
root [0] TH1F h1("hist1", "Histogram from a gaussian", 100, -3., 3.)
root [1] h1.FillRandom(
void FillRandom(const char* fname, Int_t ntimes = 5000)
void FillRandom(TH1* h, Int_t ntimes = 5000)
root [1] h1.FillRandom("gaus", 100000)
root [2] h1.Draw()
<TCanvas::MakeDefCanvas>: created default TCanvas with name c1
root [3]
```



Histograms: how to handle the content

```
TH1D h2(“hist”,”Title”,100,-3,3);
```

- Add one value at time

```
    h2->Fill(myvalue);
```

- Set the content of each bin

```
    for (Int_t i=1;i<=h2->GetNbinsX();i++)
      h2->SetBinContent(i,value[i]);
```

Notice: bin 0 contains the underflows, bin N+1 the overflows

- Retrieve the content of each bin

```
 Double_t val[i] = h2->GetBinContent(i);
```

- Total entries

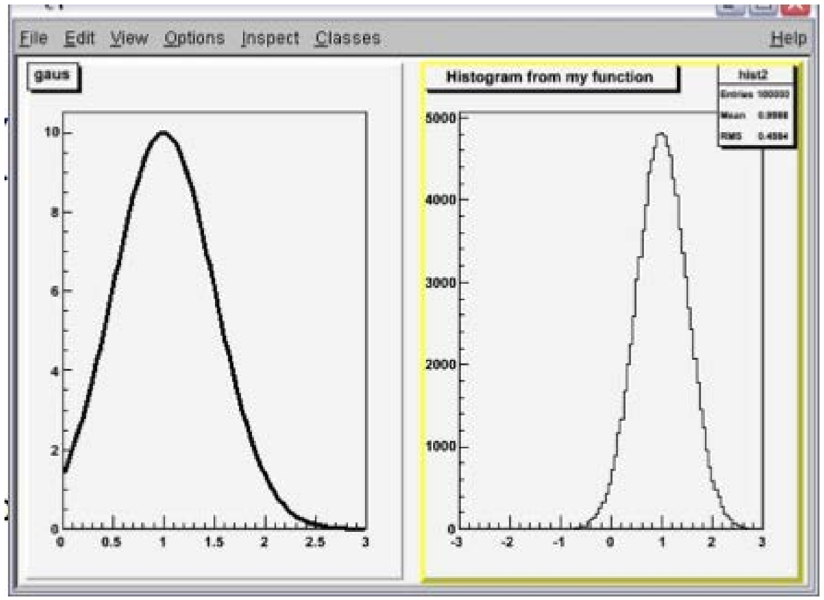
```
 Int_t entries = h2->GetEntries();
```

Example

- Fill an histogram with 100000 random numbers from the function:

$$par(0)e^{-0.5\left(\frac{x-par(1)}{par(2)}\right)^2}$$

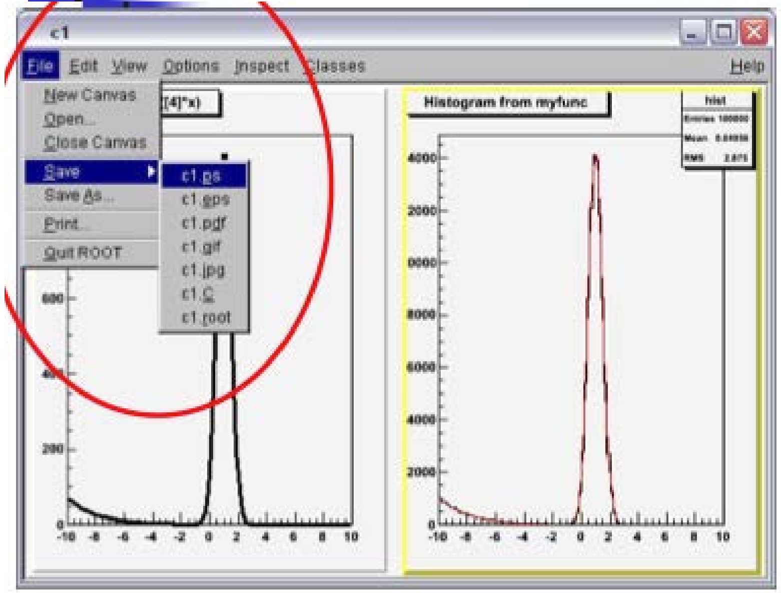
```
[ ] TF1 myfunc(“myfunc”,”gaus”,0,3);
[ ] myfunc.SetParameters(10.,1.,0.5);
[ ] TCanvas c;
[ ] c.Divide(2,1);
[ ] c.cd(1);
[ ] myfunc.Draw();
[ ] TH1D h2(“hist”,”Histo from my function”,100,-3,3);
[ ] h2.FillRandom(“myfunc”,100000);
[ ] c.cd(2);
[ ] h2.Draw();
```


File Edit View Options Inspect Classes Help
gaus
Histogram from my function
hist2
Entries 100000
Mean
RMS

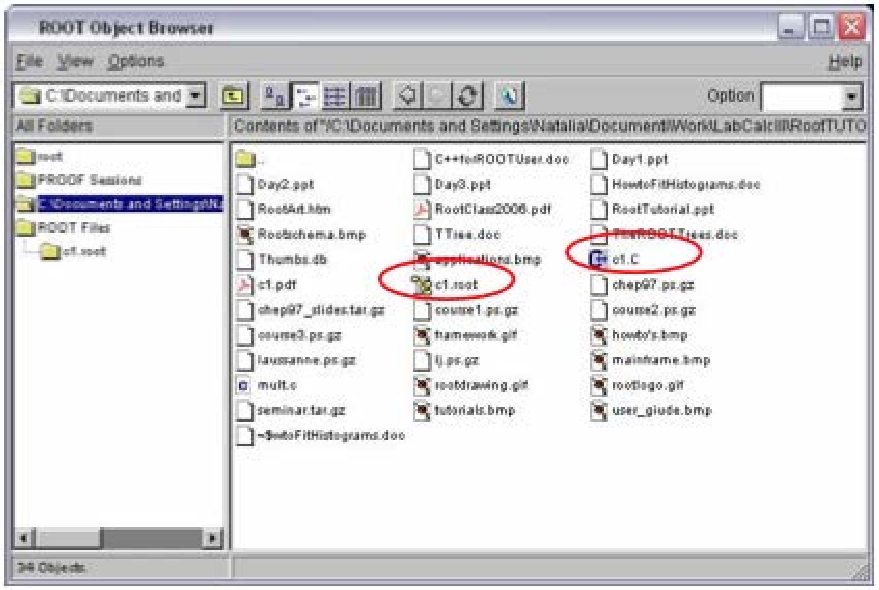
Histogram, some more extras

- Draw with error bars
  - `h1->Draw("E");`
    - Notice: by default, the error given to each bin is the square root of its content. This is **wrong** if the histogram is normalized and/or the y scale is not "counts". Can use `SetBinError(i,error)`
- Superimpose in the current Canvas
  - `h1->Draw("same")`
  - Applies also to all other ROOT objects (functions, graphs, etc.)
- Change title axis
  - `h1->GetXaxis()->SetTitle("Energy (keV)");`
- Operations on histogram(s)
  - `h1->Add(h2,1);`
  - `h1->Scale(0.01);`
- Most operations can also be done with the GUI

Save the plot with TBrowser



1) As a ROOT script **c1.C**
   Retrieve with
   `[] .x c1.C`
2) As a **graphic file**
   pdf, gif, png, ...



3) As a ROOT file **c1.root**
   It contains the ROOT objects.
   Can be retrieved from a user macro, or interactively by
   `[] TBrowser tb;`

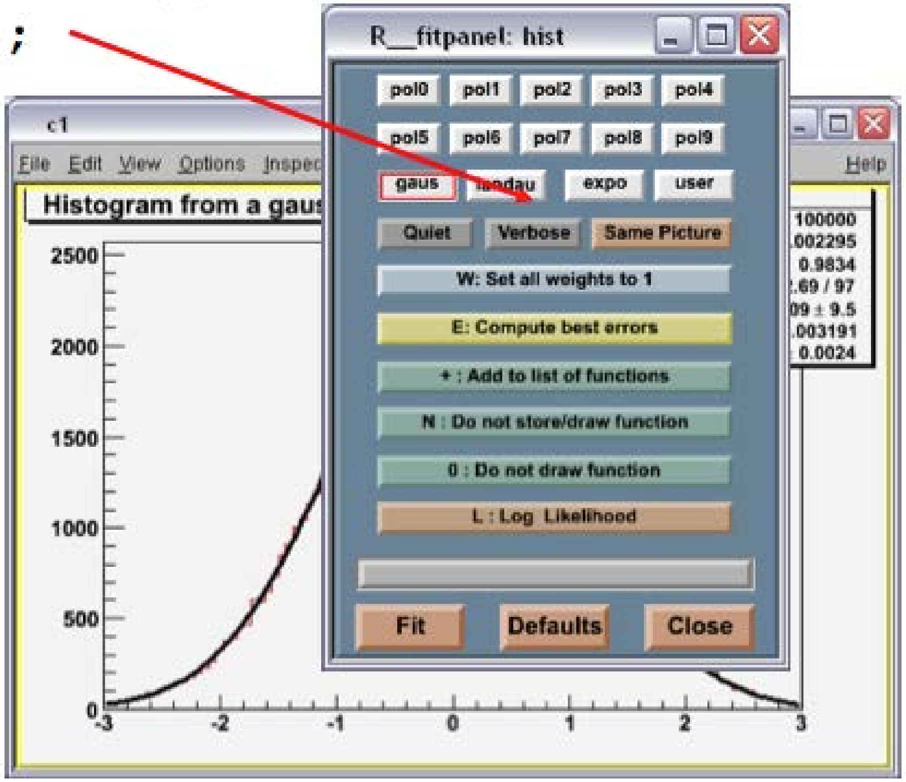
Fit of a histogram - 1

```
[ ] TH1F h1(“hist,”Histogram from a gaussian”,100,-3,3);
[ ] h1.FillRandom(“gaus”,100000);
[ ] gStyle->SetOptFit(111);
[ ] h1.Fit(“gaus”);
```

Or

```
[ ] h1.FitPanel();
```

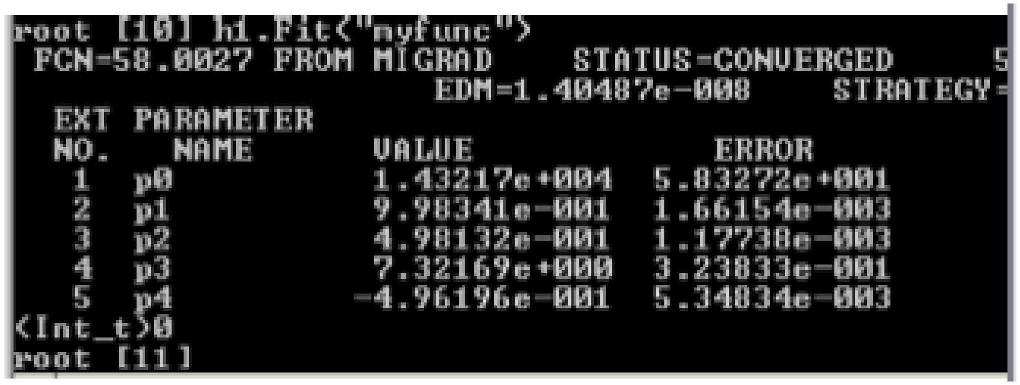
The **FitPanel** allows to choose parameters and functions in an interactive way



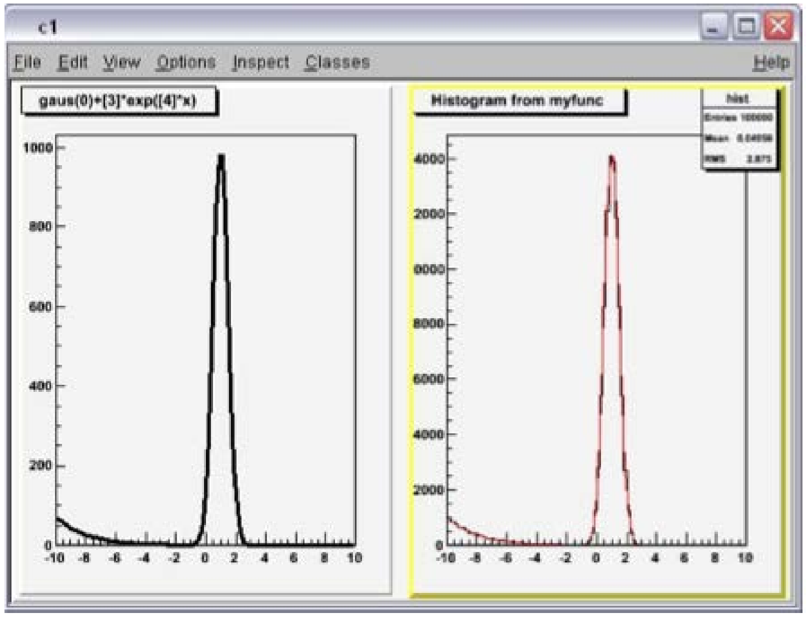
Fit of a histogram - 2

To fit an histogram with : $par(0)e^{-\left(\frac{x-par(1)}{par(2)}\right)^2} + par(3)e^{par(4)x}$

```
[ ] TF1 f1(“myfunc”,”gaus(0)+[3]*exp([4]*x)”,-10.,10.);
[ ] f1.SetParameters(1000.,1.,0.5,0.5,-0.5);
[ ] TH1F h1(“hist”,”Histogram from myfunc”,100,-10,10);
[ ] h1.FillRandom(“myfunc”,100000);
[ ] h1.Fit(“myfunc”);
```



```
root [10] h1.Fit("myfunc")
 FCN=58.0027 FROM MIGRAD    STATUS=CONVERGED      5
                     EDM=1.40487e-008     STRATEGY=
  EXT PARAMETER
  NO.   NAME        VALUE            ERROR
   1    p0          1.43217e+004   5.83272e+001
   2    p1          9.98341e-001   1.66154e-003
   3    p2          4.98132e-001   1.17738e-003
   4    p3          7.32169e+000   3.23833e-001
   5    p4         -4.96196e-001   5.34834e-003
(Int_t)0
root [11]
```



Fit of a histogram – 3

- Fit on a sub-range
  - Define the range in the **TF1 constructor**

    ```
    TF1 *g1 = new TF1("g1", "gaus", 85,95);
    ```

  - By default, TH1::Fit on the defined histogram range. Use "**R**" option in the Fit() method.

    ```
    h->Fit("g1", "R");
    ```

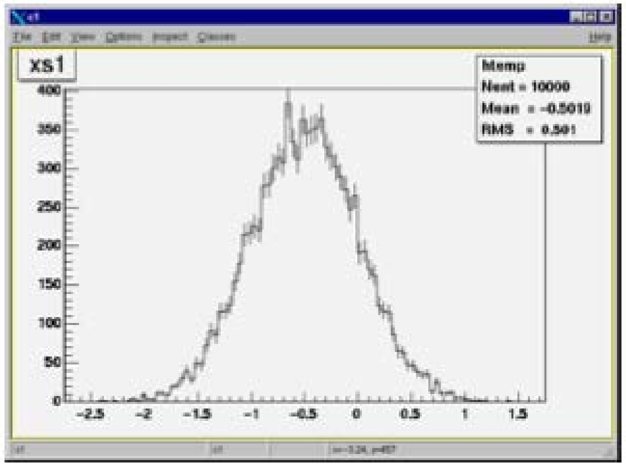
  - Can "merge" different functions in different sub-ranges
- Retrieve fit function and parameters
  - Fit function attached to the histogram

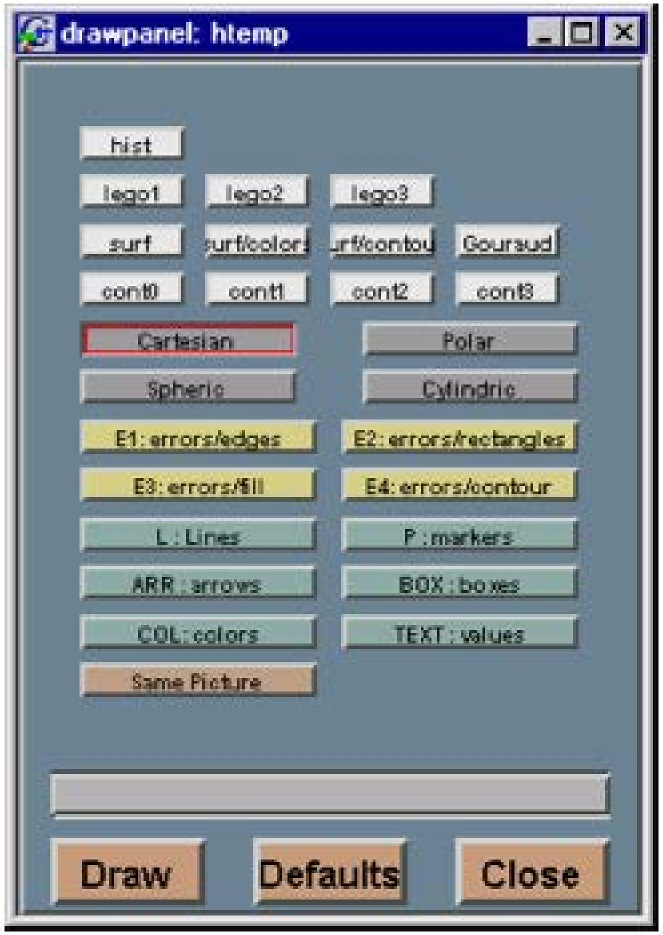
```
TF1* fun = h->GetFunction("g1");
cout << fun->GetParameter(0) << " +/- " <<
   fun->GetParError(0) << endl;
fun->SetParLimits(1,-10,10);
```

The DrawPanel()

- The interactive panel:
  - `h1 -> DrawPanel();`

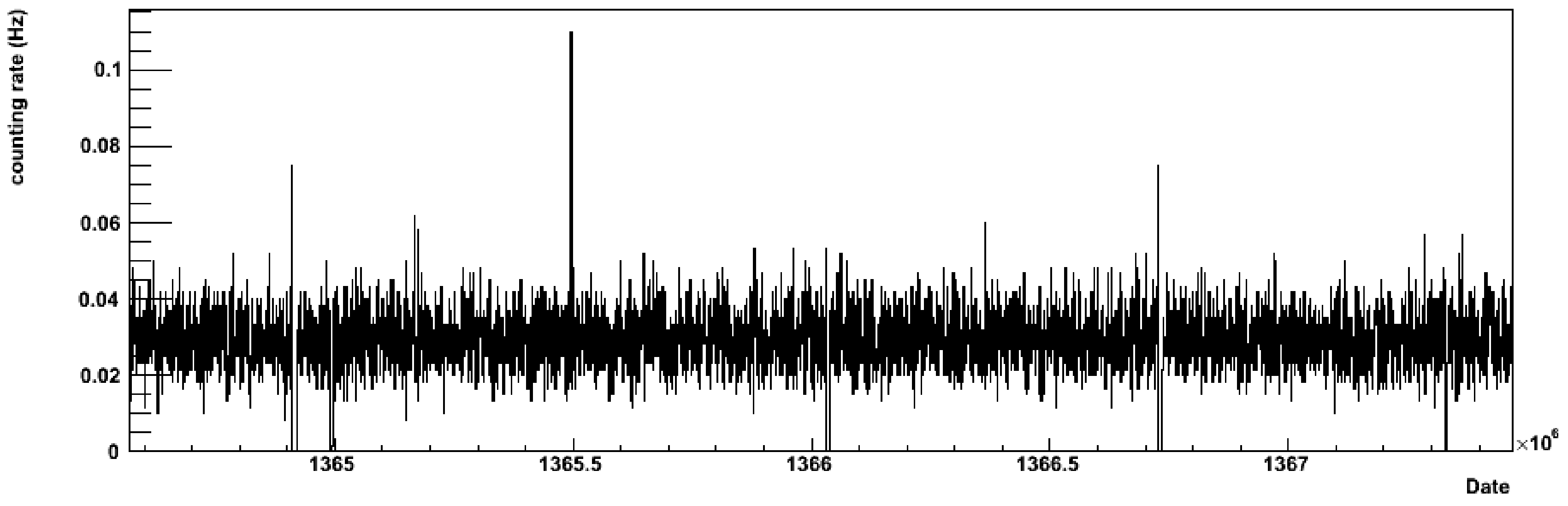
It allows to change parameters/type of histogram, coordinates, errors, colors, etc.





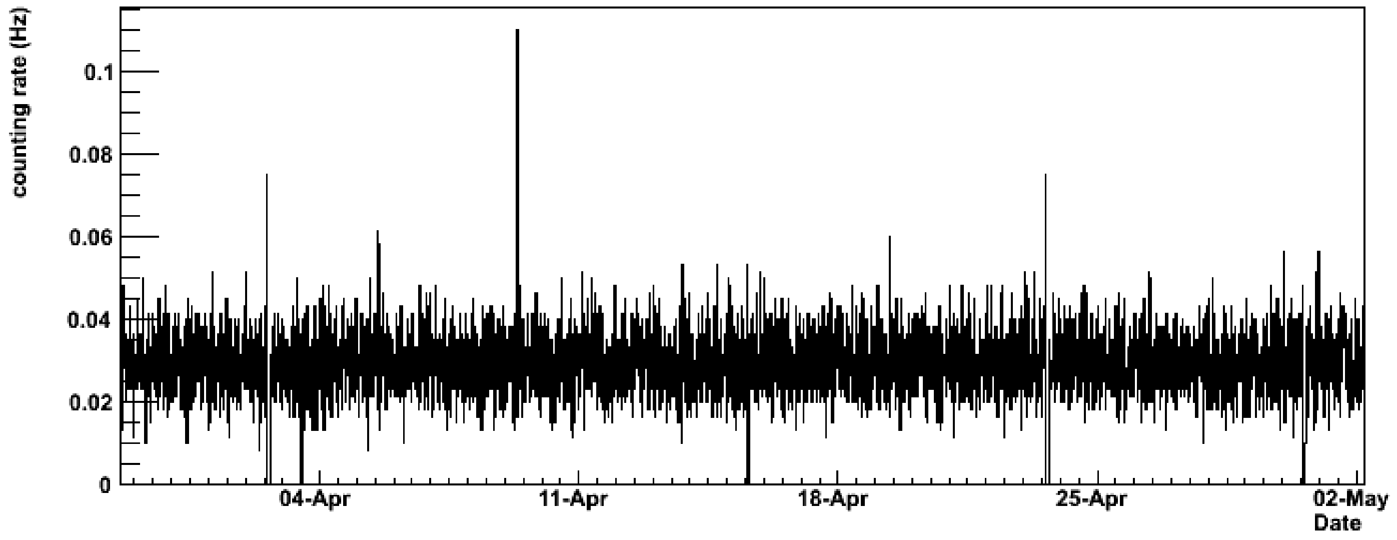
Time axis - 1

- In some cases, the quantity of one axis is date/time
  - Typical case: UNIX time stamp (number of seconds elapsed since 1/1/1970)
  - E.g. Jun 1st 2014 00:00:00 GMT → 1401580800
- Want to have a *more meaningful* x-axis scale!



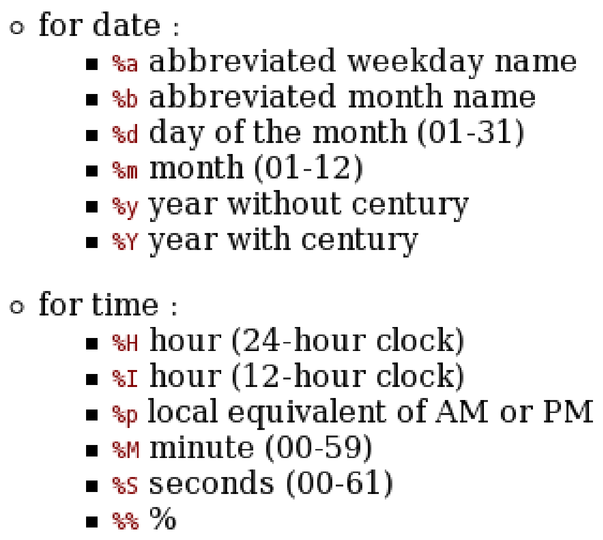
Time axis - 2

- Use time axis option
  - **`h1->GetXaxis()->SetTimeDisplay()`**
- Set the format and the time offset
  - Default: time elapsed since 1/1/1995
  - **`h1->GetXaxis()->SetTimeFormat("%d-%b %F1970-01-01 00:00:00");`**

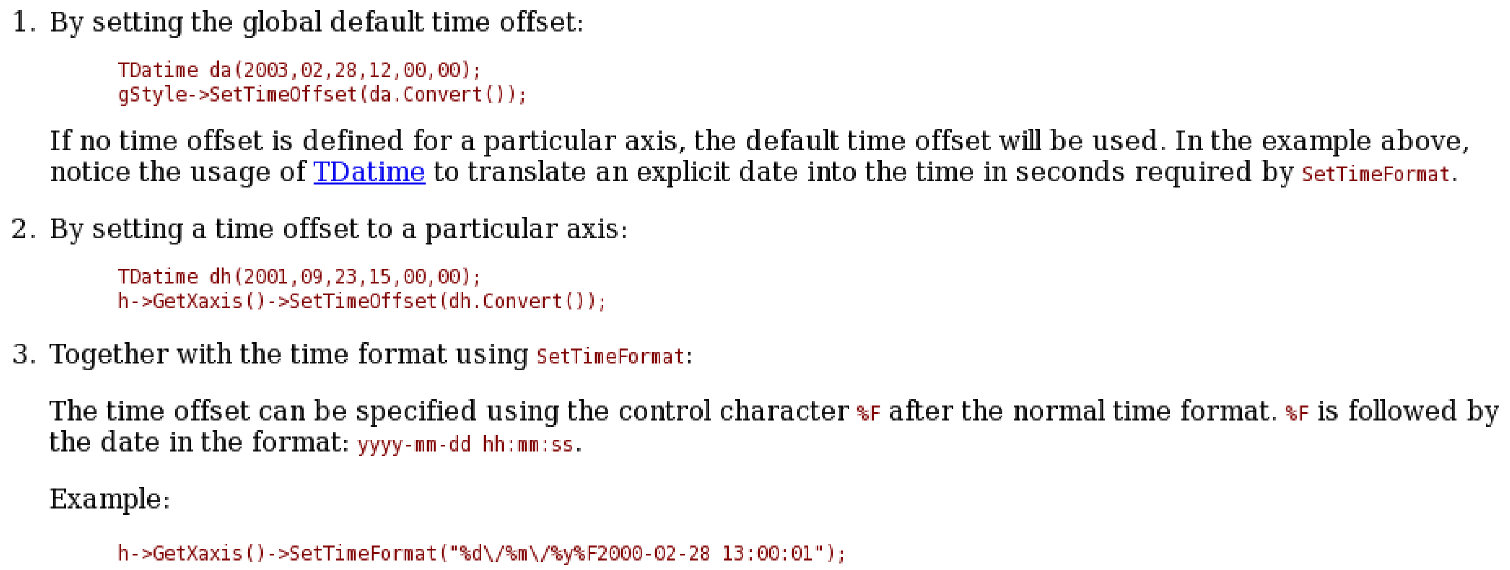


Time axis - 3

- Check the documentation online for the possible formats of date/time
- Same applies for offsets



- for date :
  - `%a` abbreviated weekday name
  - `%b` abbreviated month name
  - `%d` day of the month (01-31)
  - `%m` month (01-12)
  - `%y` year without century
  - `%Y` year with century
- for time :
  - `%H` hour (24-hour clock)
  - `%I` hour (12-hour clock)
  - `%p` local equivalent of AM or PM
  - `%M` minute (00-59)
  - `%S` seconds (00-61)
  - `%%` %



1. By setting the global default time offset:

   ```
   TDatime da(2003,02,28,12,00,00);
   gStyle->SetTimeOffset(da.Convert());
   ```

   If no time offset is defined for a particular axis, the default time offset will be used. In the example above, notice the usage of TDatime to translate an explicit date into the time in seconds required by `SetTimeFormat`.

2. By setting a time offset to a particular axis:

   ```
   TDatime dh(2001,09,23,15,00,00);
   h->GetXaxis()->SetTimeOffset(dh.Convert());
   ```

3. Together with the time format using `SetTimeFormat`:

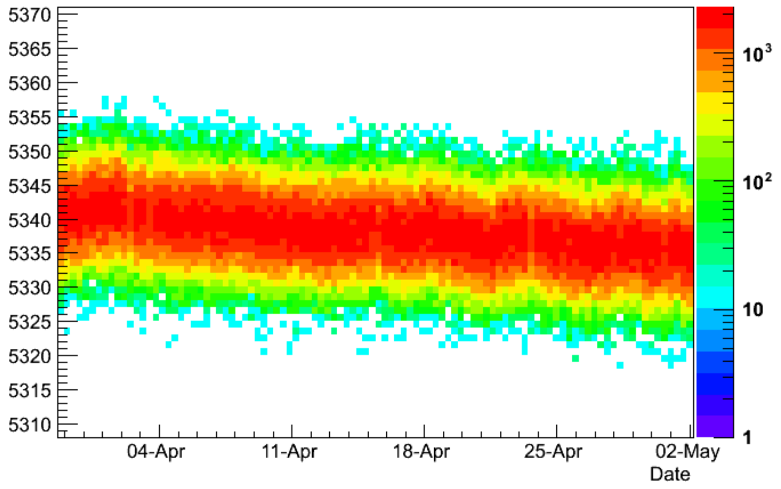
   The time offset can be specified using the control character `%F` after the normal time format. `%F` is followed by the date in the format: `yyyy-mm-dd hh:mm:ss`.

   Example:

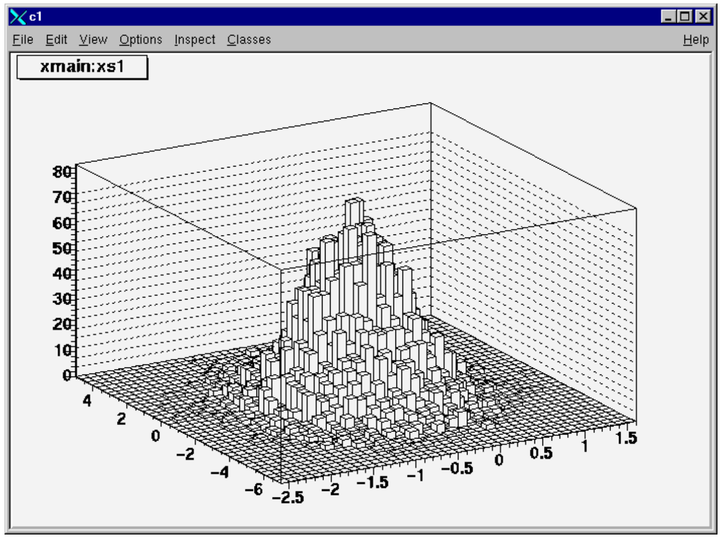
   ```
   h->GetXaxis()->SetTimeFormat("%d\/%m\/%y%F2000-02-28 13:00:01");
   ```

2-dimensional histograms

- Class TH2* (TH2D, TH2F, ...)
  - Very same methods inherited from the basic TH1 interface (plots, fits, etc.)
  - Extra options for plotting (contour, lego, colour code, ...)
  - Have a z-axis now!
    - **`c1->SetLogz()`**

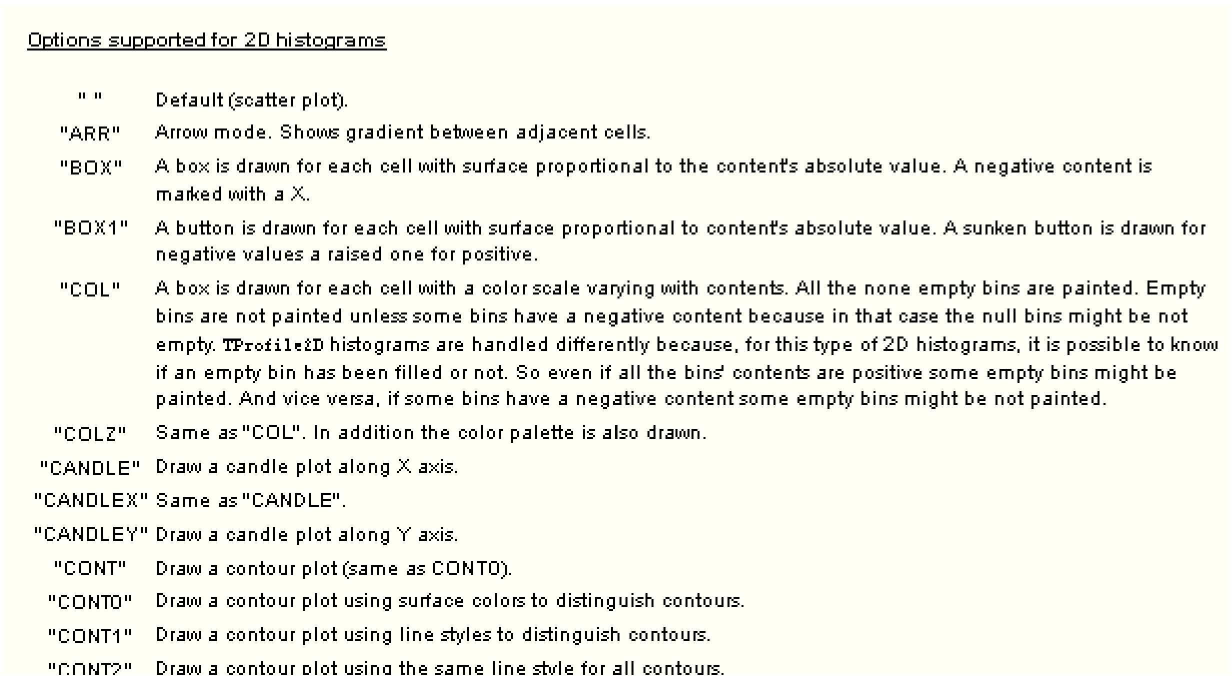


Rotate with the mouse



Histogram drawing options

- Check the **THistPainter** documentation for all available options
- Most options also available from the GUI



Options supported for 2D histograms

" "	Default (scatter plot).
"ARR"	Arrow mode. Shows gradient between adjacent cells.
"BOX"	A box is drawn for each cell with surface proportional to the content's absolute value. A negative content is marked with a X.
"BOX1"	A button is drawn for each cell with surface proportional to content's absolute value. A sunken button is drawn for negative values a raised one for positive.
"COL"	A box is drawn for each cell with a color scale varying with contents. All the none empty bins are painted. Empty bins are not painted unless some bins have a negative content because in that case the null bins might be not empty. `TProfile2D` histograms are handled differently because, for this type of 2D histograms, it is possible to know if an empty bin has been filled or not. So even if all the bins' contents are positive some empty bins might be painted. And vice versa, if some bins have a negative content some empty bins might be not painted.
"COLZ"	Same as "COL". In addition the color palette is also drawn.
"CANDLE"	Draw a candle plot along X axis.
"CANDLEX"	Same as "CANDLE".
"CANDLEY"	Draw a candle plot along Y axis.
"CONT"	Draw a contour plot (same as CONT0).
"CONT0"	Draw a contour plot using surface colors to distinguish contours.
"CONT1"	Draw a contour plot using line styles to distinguish contours.
"CONT2"	Draw a contour plot using the same line style for all contours.

Random generators and math libraries

TMath

- Large library of mathematical tools
  - Numerical constants
    - π = TMath::Pi(), 1/π = TMath::InvPi(), ...
  - Trigonometric and elementary math functions
    - Sin, cos, log(s), power, asin, ...
  - Functions and tools to work with arrays and collections
    - Sort, binary search, max, min, ...
  - Statistical and special functions
    - Breit-Wigner, Bessel, KolmogorovProb, χ^2 quantiles
- Can be used by command line and in scripts

```
TF1*
f1("f1","TMath::ASin(x)*TMath::Log10(x)",1,
10);
```

TRandom - 1

- Random number generators embedded in ROOT
  - Can be used by command line and (mostly) compiled/interpreted scripts
- A few generators available, differing for the "quality" of the random numbers and for the CPU time

Not to be used for real statistical studies

TRandom	34	ns/call	(BAD Generator)
TRandom1	242	ns/call	CERN RANLUX
TRandom2	37	ns/call	
TRandom3	45	ns/call	Mersenne Twister generator

TRandom - 2

- A few commonly-used distributions provided

```
TRandom3 rd;
Double_t val = rd.Exp(tau);
Int_t n = rd.Poisson(mean);
```

  - `Integer(imax), Gaus(mean,sigma), Rndm(), Uniform(), Landau(mpv,sigma), Binomial(ntot,prob)`
  - Able to handle/change random seed
- Can generate random numbers according to a given histogram or function

```
TF1* f1("f1","abs(sin(x))*sqrt(x)",0,10);
Double_t val = f1.GetRandom()
```