Introduction to ROOT

ROOT: object-based development environment dedicated to data analysis, and based mostly on C++

www : root.cern

Modes of work

- Interactive (terminal session)
  - ▻ online-interpretted C++ commands
  - ▻ macros (interpretted or compiled), two possible modes:
    - – simplified: just commands in a file
    - – within functions ; more conformity to C++ standards required
- As compilable C++ code : using Root libraries

Includes:

- Graphical windows, histograms, scatter plots (with uncertainties)
- Mathematical function (including special functions) : drawing, evaluation, pulling from distributions
- Fitting of functions to data
- Data bases ("trees") , Data filtering ("cuts")
- Pulling from random distributions
- Collections of objects, I/O with storage of objects
- Numerical algorythms, analysis of spectra
- DataFrame – type programming
- Machine learning ("TMVA")
- GUI building, Multithreading

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Guides, manuals, help

- Help TOC: root.cern/get_started/
- Manual: root.cern/manual/
- Primer: root.cern/primer/
- Slides indico.cern.ch/event/395198/attachments/791523/1084984/ROOT_Summer_Student_Tutorial_2015.pdf
- Forum: root-forum.cern.ch
- Documentation: root.cern/doc/master/

Notice: class names in this script are clickable and point to relevant ROOT help pages :)

Installation:

- Download: root.cern/install/#download-a-pre-compiled-binary-distribution
  sources or binaries for: Linux, Windows, Mac
- Linux: Go to your login script (`~/.bash_login` or `~/.bashrc`) and add line:

```
. [your_ROOT_path]/bin/thisroot.sh
```

- Quantum jump:

Versions ≤ 5.34	vs	Versions ≥ 6.00
"`cint`" interpretter		"`cling`" interpretter
Syntax tolerance		Syntax rigor
Standard: ~ C++98		Standard ~ C++11

MODE I: Interactive session ROOT as a calculator and interpretter of C++ commands

- Launching:
  - `root`
  - `root -l` (without 'welcome' splash screen)
  - `root -b` (without graphics, but faster instead)

- Inside session.
  - Quitting: `.q`
  - Shell command: `.! {your command}`
  - Executing a macro: `.x`
  - Forced exit: `.qqqqqqqq`

```
root [0] sqrt (1.23)
(const double)1.10905365064094164e+00
root [1] double x = pow (sin(0.5),2.) + pow (cos(0.5),2.)
root [2] x
(double)1.00000000000000000e+00
root [3] cout << x << endl
1
(class ostream)139768533438272
```

Data types

① C++ types: `int, double, char text[100], string napis, vector<double> vec, double* d, int& i, ...`

② Internal (ROOT) types, as overlays on the C++ types:

`Int_t , Float_t , Double_t, Char_t, Bool_t`

Motivation: making the code machine-indepent

List of machine-independent types:

root.cern/root/htmldoc/guides/users-guide/ROOTUsersGuide.html#machine-independent-types

TMath — Mathematical class (Notice: class names are links to help sites)

- Functions (`TMath::Sqrt(x) , Power, SinH, Exp, Gaus, Factorial, ...`)
- Mathematical and physical constants (`TMath::Pi(), E, RadToDeg, DegToRad, Hbar, K`)
- Operations (`TMath::Abs(x) , Min, Max, ...`)
- Special functions (`TMath::BesselI (x) , BesselJ/K/Y , Erf, ...`)

```
root [0] TMath::Power (TMath::Pi() , 1./3.)
(Double_t)1.46459188756152314e+00
```

Notice: The `ROOT::Math` namespace containes even more functions and algorithms



Autocompletion – intelligent handy help

```
root [1] TMath::Pi
Pi
PiOver2
PiOver4
root [1] TMath::Pi(

Double_t Pi()
root [1] TMath::Power(

LongDouble_t Power (LongDouble_t x, LongDouble_t y)
LongDouble_t Power (LongDouble_t x, Long64_t y)
LongDouble_t Power (Long64_t x, Long64_t y)
Double_t Power (Double_t x, Double_t y)
Double_t Power (Double_t x, Int_t y)
```

TCanvas — Graphical window

```
root[0] new TCanvas                          ← "quick" creation of graphical window with generic properties
(class TCanvas*)0x2c1e5e0                    ← Notice: automatic name assignment ("c1")
root[1] c1->Set <Tab>

root[1] c1->SetTitle ("HelloCanvas")
root[2] c1->GetTitle ()
(const char* 0x1557339)"HelloCanvas"
root[3] c1->ls ()
root[4] c1->Close()
root[5] TCanvas c2                           ← We create a new window. Before we used pointer. Now – object.
root[6] c2.GetName()
(const char* 0x16632b1)"c1_n2"               ← Title is different than variable name!
root[7] TCanvas c3 ( <Tab>
```

Multitude of constructors

```
TCanvas TCanvas (Bool_t build = kTRUE)
TCanvas TCanvas (const char* name, const char* title = "", Int_t form = 1)
TCanvas TCanvas (const char* name, const char* title, Int_t ww, Int_t wh)
TCanvas TCanvas (const char* name, const char* title, Int_t wtopx, Int_t wtopy,
Int_t ww, Int_t wh)
TCanvas TCanvas (const char* name, Int_t ww, Int_t wh, Int_t winid)
root[7] TCanvas c3 ("c3canvas", "My canvas", 600, 400);
```

Proper name of object (within C++).

"Name" (identifier) (within ROOT)

Displayed title (just a c-string)

```
root[8] c3Canvas
(class TCanvas*)0x16964d0
root[9] TCanvas* c4 = new TCanvas ("c4canv", "2nd Canvas", 600, 400);
```

Name as identifier or replacement of C++ name

Dynamic allocation (we then use a pointer to an object)

TFn n = {1, 2, 3} Functions

```
root[0] TF1 f1 ("f1", "sin(x)/x", 0. , 10. );
root[1] f1.Draw ()
root[2] f1.SetRange (-10. , 10.)
root[3] f1.Draw ()
root[4] f1.Eval (1.)    or    f1(1.)
root[5] f1.Integral ( 0. , TMath::Pi() )
root[6] f1.GetMinimum ( 1e-10 , 5.)
```

← function with given formula and range

```
root[7] TF1 f2 ("f2", "[0]*sin([1]*x)/x", 0., 10.);
root[8] f2.SetParameter (0, 0.5);
root[9] f2.SetParameter (1, 2. );
root[10] f2.Draw ("same")

root[11] f2.SetLineColor (2);
```

← parameter-dependent function

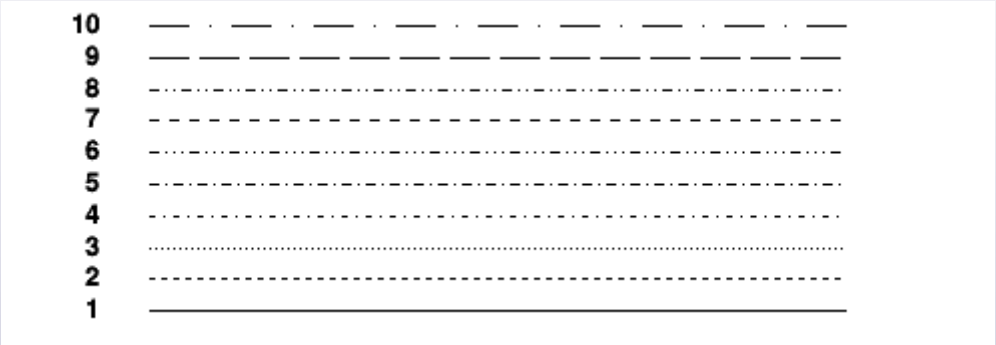


Color numbering scheme for the generic palette

```
root[12] f1.SetLineWidth (2);

root[13] f1.SetLineStyle (2);

root[14] f1.Draw ("same");
```



Numbering scheme of line styles

```
root[15] TF2 f3 ("f3", "exp( -(x-0.5)*(x-0.5)/0.05 - (y-0.5)*(y-0.5)/0.05) ");
root[16] f3.Draw ()
root[17] f3.Draw ("lego2")
root[18] f3.Draw ("colz")
```

← Graphical options, e.g.: `"surf", "surf2", "cont"`

root.cern/doc/master/classTHistPainter.html#HP01

(*Notice*: more methods of declaring functions are available in C++ macros.)

Saving a graphical window in a file:

```
root[10] c1.Print ("picture.ext");
```

ext = {gif, jpg, pdf, png, (e)ps, svg, root, tex, tiff, xml, xpm, json cxx}

Caution: lossy -vs- lossless formats of graphics storage

How to create **multipage** pdf (and ps) files.

Imagine that we have 3 × TF1 to plot (separately) on TCanvas c1.

```
root[1] f1.Draw() ; c1->Print ( "MyPortfolio.pdf(" );
root[2] f2.Draw() ; c1->Print ( "MyPortfolio.pdf"  );
root[3] f3.Draw() ; c1->Print ( "MyPortfolio.pdf)" );
```

Clearing the TCanvas:

```
root[4] c1->Clear ();
```

TGraph Scatter plots of data points

(and related ones: TGraphErrors / TGraphAsymmErrors / TGraphBentErrors)

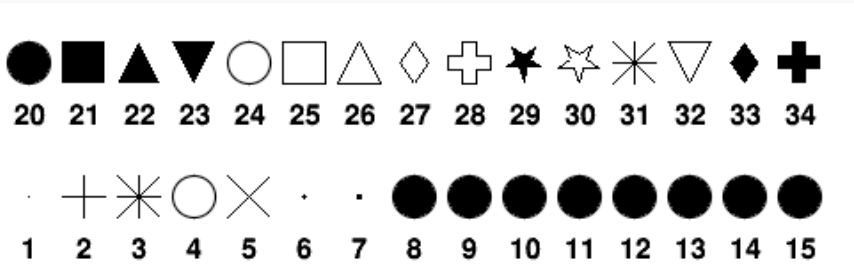
In a Linux console: `wget www.fuw.edu.pl/~kpias/ctnp/tgraph.dat`

tgraph.dat

```
0.0 0.01
0.1 0.98
0.2 2.03
0.3 2.99
0.4 4.07
0.5 5.01
```

```
root[1] TGraph g ("tgraph.dat")
root[2] g.Draw ("AP")

root[3] g.SetMarkerSize (0.8)
root[4] g.SetMarkerStyle (20)
root[5] g.Draw ("AP")
```



Marker styles

You can select which columns to read:

`wget www.fuw.edu.pl/~kpias/ctnp/tgraph2.dat`

```
root[1] TGraph g ("tgraph2.dat", "%*s %lg %*lg %lg" );
root[2] g.Draw ("AP");

root[3] TGraph g2(
(…)
TGraph TGraph (Int_t n, const Double_t* x, const Double_t* y)
TGraph TGraph (Int_t n, const Float_t* x, const Float_t* y)
(…)
root[4] Double_t x[] = {0.05, 0.95, 1.95, 2.05, 3.05, 3.95};
root[5] Double_t y[] = {1.00, 1.11, 1.29, 1.41, 1.52, 1.59};
root[6] TGraph g2 (6, x, y);
root[7] g2.SetMarkerSize (0.8) ; g2.SetMarkerStyle (22) ; g2.SetMarkerColor (2)
root[8] g2.SetMinimum (0.) ; g2.SetMaximum (5.5)
root[9] g2.GetXaxis()->SetLimits (0, 5);
root[10] g2.Draw ("AP")
root[11] g.SetMarkerSize (0.8) ; g.SetMarkerStyle (24) ; g.SetMarkerColor (4)
root[12] g.Draw ("sameP")
```

`%lg` : read column as double precision
`%*lg`: column type is double; omit it.
`%*s` : column type is string; omit it.

TRandomN , *N* = { 1, 2, 3 } Pseudorandom numbers

- Usage of *TRandom3* is advised in the documentation. Calling time ~ 45 ns. Period ~ 10^{6000} .

```
root[1] TRandom3 r;
root[2] r.SetSeed ();          ← initializing the seed of pseudorandom generator
```

- TRandomN have predefined distributions, e.g. :

```
Binomial (ntot, prob)          BreitWigner (mean, gamma)
Exp (tau)                      Integer (imax)
Landau (mean, sigma)           Gaus (mean, sigma)
Rndm ()   ← returns double ∈ [0, 1)   Poisson (mean)
```

```
root[3] r.Rndm ()
(Double_t) 9.997417e-01
root[4] r.Gaus (15.3, 0.02)
(Double_t) 1.531998e+01
```

- Moreover, you can pull numbers from distribution defined by the user in form of TF1 object, e.g. :

```
root[5] TF1 fun1 ( "fun1", "x*x*exp(-x/0.5)" , 0., 5.) ;
root[6] fun1.GetRandom ()
(Double_t) 6.916067e-01
```

- You can also pull a number from an user-defined histogram (description of histograms – soon).

TVectorN , $N = \{2, 3\}$ 2-3 dimensional vectors

```
root[1] TVector3 v1 (1, 2, 3) , v2, v3;
root[2] v2.SetXYZ (-1,-2,-3);

        v1.Mag()  Mag2()   Theta()  CosTheta()  Phi()  Perp()   ← basic properties

root[3] v3 = -3. * (v1 + v2);  v3 -= 2. * v1;  v3.Print()
root[4] v1.Cross(v2) .Print();                  ← cross product
root[5] v1.Dot ( v3.Orthogonal () )             ← dot product;  perpendicular vector

        v1.Angle (v2);    v1.RotateX/Y/Z (angle);  v3.Rotate (angle, v2)
```

TLorentzVector Four-vector

Has 4 dimensions, that you can use either as $[X, Y, Z, T]$ or $[P_x, P_y, P_z, E]$. (*Caution*: sequence!)
It is implemented as `TVector3 ⊕ double` .

```
root[1] TLorentzVector L (1, 2, 3, 4); cout << L.T() << endl;

        L.Pt() P()          ← √(P_x² + P_y²) , |P⃗|
        L.M()               ← ±√(spacetime interval) / ±available energy / ±invariant mass
        L.Beta() Gamma()    ← β = ±|P⃗|/E,  γ = 1/√(1 − β²)

root[2] TLorentzVector v4piplus (0., 0., 1., sqrt(1*1 + 0.1395*0.1395) );
root[3] v4piplus.Rapidity();    ← y = 0.5 · ln [(E−p_z)/(E+p_z)]

root[4] TVector3 beta (0., 0., 0.7);
root[5] v4piplus.Boost (beta);        ← Apply Lorentz transform by "beta" velocity vector
root[5] v4piplus.BoostVector().Z()    ← Retrieve velocity vector, then its Z^th component
```

Histograms

THdt, *d* = {1, 2, 3}
t = {C, S, I, F, D}

Type of variables that stores the bin content
Dimension of histogram

Type	C	S	I	F	D
Max bin content	$2^8 - 1$	$2^{16} - 1$	$2^{31} - 1$		
Max precision				7 digits	14 digits

No of bins From To

```
root[1] TH1F h1 ("hist1", "My histogram", 100, -10., 10.);
root[2] h1.Fill (5.23);
root[3] h1.Draw ();
root[4] h1.Fill (3.21, 0.1); h1.Draw ();
root[5] h1.Draw ("hist");

root[6] TRandom3 r;  r.SetSeed ();
root[7] for (int i=0; i < 1e5 ; i++)  h1.Fill ( r.Gaus() );
root[8] h1.Draw ();
```

Fill the bin containing *x* = 5.23, with weight of 1.

Fill the bin containing *x* = 3.21, with weight of 0.1.

Drawing options:

For TH1_ : `"same", "e", "e0 … 4", "hist", …`

For TH2_ : `"box", "col", "cont", "lego", "surf"` (+ other options, e.g. `"lego2"`)

→ root.cern/root/htmldoc/guides/users-guide/ROOTUsersGuide.html#draw-options

Options can be combined, e.g. `h.Draw ("colz") , h.Draw ("e1same")`

Histograms, cont.

```
root[1] h1.Set <Tab>

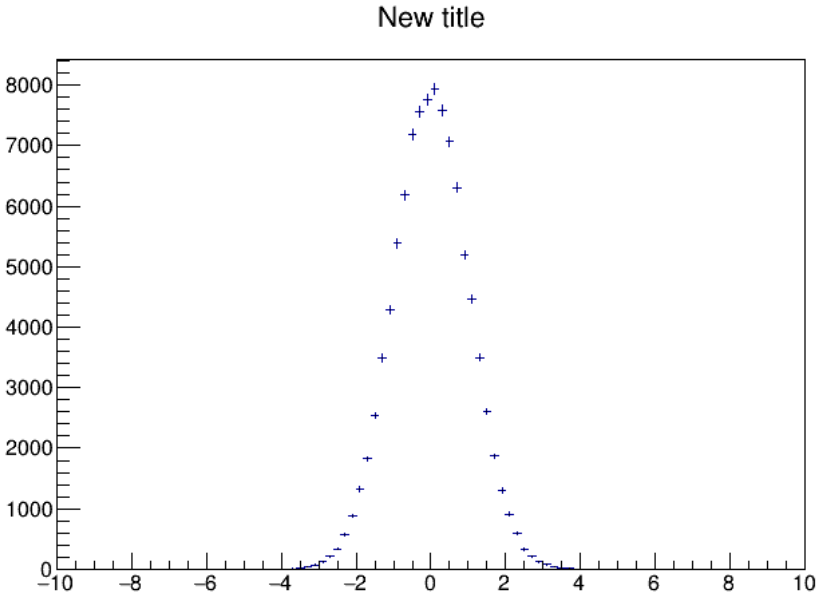
root[1] h1.SetTitle ("New title")
root[3] h1.SetLineColor (…) / SetLineStyle (…) / SetLineWidth (…)

root[4] h1.SetStats ( 0 / 1 );        ← (Don't) plot stats (for details, see description of TStyle)

        h1.SetNdivisions ( code , " Axis " );
```

Code = `N1 + 100*N2 + 10000*N3`, where:

N1: (expected) number of leading divisions
N2: (expected) number of 2. rank divisions
N3: (expected) number of 3. rank divisions



Summing up the counts: <Tab>

```
root[5] h1.Integral (

Double_t Integral (Int_t binx1, Int_t binx2,
                   Option_t* option = "" )
```

We have a problem. How to find the bin index that corresponds to a given *x* ? → `FindBin (x)` method.

```
root[6] h1.Integral ( h1.FindBin (-3.) , h1.FindBin ( 3.)  )
```

Caution: by default this method does not integrate ($\Sigma h_i \cdot \Delta$) but sums up the contents of bins (Σh_i).
To calculate the integral, you have to add `"width"` as an option.

Histograms, cont.

```
root[4] h1.Get <Tab>
root[4] cout << h1.GetMean() << '\t' << h1.GetRMS() << '\t' << h1.GetNbinsX();
```

You can retrieve the **max**imal/**min**imal **bin-content** of histogram, and the **index of a bin** that contains it:

```
root[5] cout << h1.GetMaximum() << '\t' << h1.GetMaximumBin() << endl;
7834    50
```

To define the range of Y axis drawn, by default ROOT sets up minimum to 0 and maximum to ≈10% above the max bin-content. You can change this range using `SetMaximum/SetMinimum (value)`:

```
root[2] h1.SetMinimum (-20) ; h1.SetMaximum (200)
```

Side effect: since now `h1.GetMaximum()` will show `200`.

Histograms, cont.

- Access to histogram data.

Bin numbering convention: [1 … h1.GetNbinsX()]

```
root[1] cout << h1.GetBinContent (41) <<'\t'<< h1.GetBinError (41) << endl;
11  3.31662
```

As you can see, uncertainties are Poissonian

```
root[2] Float_t* hy = h1.GetArray ()
```

Will return the array with bin contents
Attention for the numbering: hy[1] … hy[N]
In hy[0] , hy[N+1] the *underflow / overflow* are stored

- Unfortunately, there is no method directly extracting the array of uncertainties. Instead you can:

```
root[3] Float_t* hyerr = new Float_t [ h1.GetNbinsX() + 2 ]
root[4] for (int i=0; i<= h1.GetNbinsX()+1; i++) hyerr[i] = h1.GetBinError(i)
```

- You can also extract the array of X coordinates of centers of bins:

```
root[5] Float_t* hx = new Float_t [ h1.GetNbinsX() + 2 ]
root[6] for (int i=0; i<= h1.GetNbinsX()+1; i++) hx[i] = h1.GetBinCenter (i)
```

- To create a separate data structure for uncertainties, issue this before filling the histogram:

```
root[7] h1.Sumw2 ()
```

Histograms, cont.

Operations on histograms (Addition, multiplication, division)

```
root[1] TH1F::Add ( <Tab>

Bool_t Add (TF1* h1, Double_t c1 = 1, Option_t* option = "")
Bool_t Add (const TH1* h, const TH1* h2, Double_t c1 = 1, Double_t c2 = 1)
Bool_t Add (const TH1* h1, Double_t c1 = 1)
```

*this = c1*h + c2*h2*

*this += c1*h1*

```
root[2] TH1F h2 (h1); h2.Reset()
```

New histogram: such as h1, but empty.

```
root[3] for (int i=0; i < 1e5 ; i++)  h2.Fill ( r.Gaus (5., 1.) );
```

Filling with Gauss distrib.

```
root[4] h2.Draw();  h2.Add ( &h1 , 0.1 );  h2.Draw ("e1")
```

Add to h2 h1 weighted by 0.1

```
root[5] TH1F h3 (h1); h3.Reset()

root[6] for (int i=1; i<1000; i++) h3.Fill (-9.99 + 0.02*i) ;
```

Uniform distribution

```
root[7] h2.Multiply ( &h3 )
root[8] h2.Draw ("e1")
```

Multiply h2 by h3, storing in h2.

Uncertainties follow the propagation formula

```
root[9] TH1F h4 (h1); h4.Reset ()
root[10] h4.Divide ( &h2 , &h3 )
root[11] h4.Draw ("e1")
```

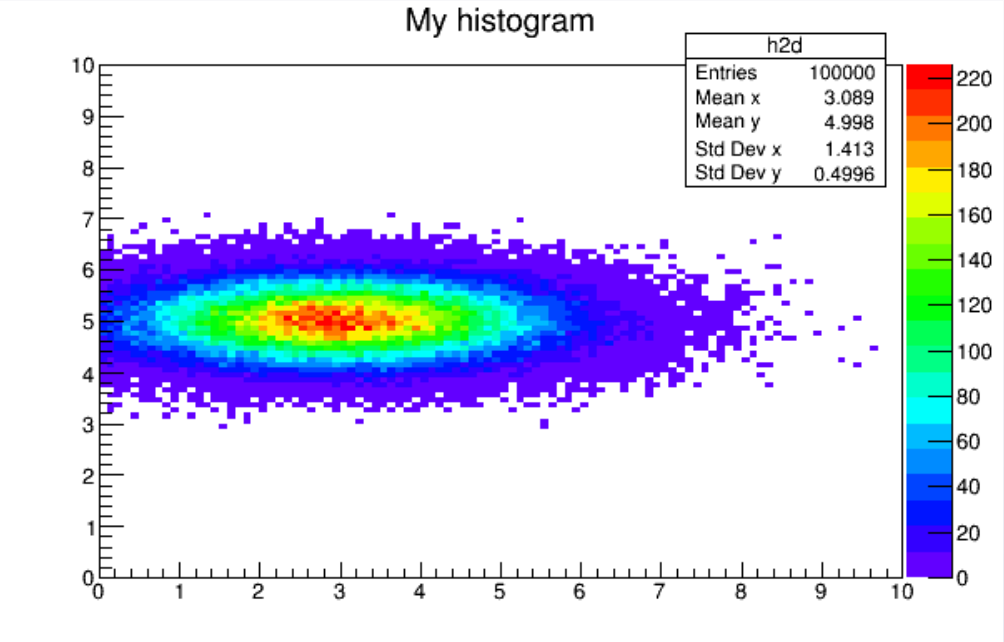
Divide h2 by h3, but store in h4.

Uncertainty arose, not cancelled out, as expected

2-Dim Histograms

X AXIS: No of bins, From, To — Y AXIS: No of bins, From, To

```
root[0] TRandom3 r;  r.SetSeed ();
root[1] TH2F h2d ("h2d", "My histogram", 100, 0., 10., 100, 0., 10.);
root[2] for (int i=0; i<1e5; i++)  h2d.Fill ( r.Gaus(3,1.5) , r.Gaus(5,0.5) );
root[3] h2d.Draw ("colz")
```




```
root[4] cout << h2d.GetNbinsX() << '\t' << h2d.GetNbinsY() << endl;
100     100
```

- Access to **axis range**, **number of bins** and **bin width** (for any axis): object of **TAxis** class

```
root[5] TAxis* ax = h2d.GetXaxis () , * ay = h2d.GetYaxis ();
root[6] cout << ax->GetXmin() <<' '<< ax->GetXmax() <<' '<< ax->GetNbins()<< endl;
root[7] cout << ay->GetXmin() <<' '<< ay->GetXmax() <<' '<< ay->GetNbins()<< endl;
root[8] cout << ax->GetBinWidth(1) <<' '<< ay->GetBinWidth(1) << endl;
```

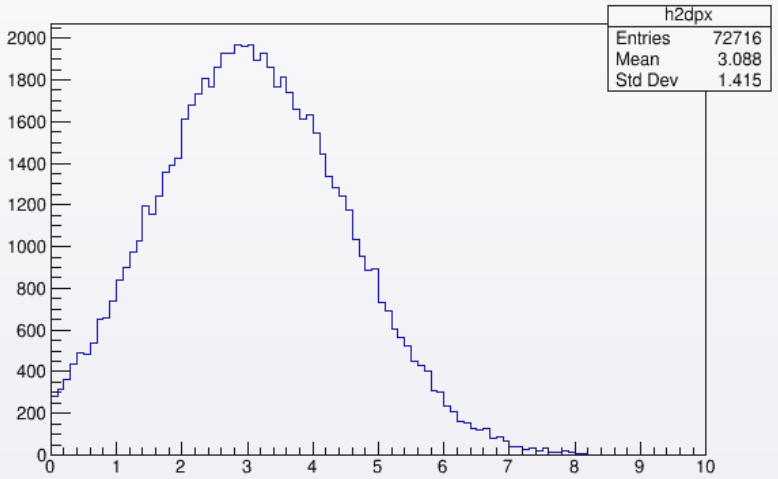
Histograms cont.

2dim → 1dim projections (into X axis or Y axis)

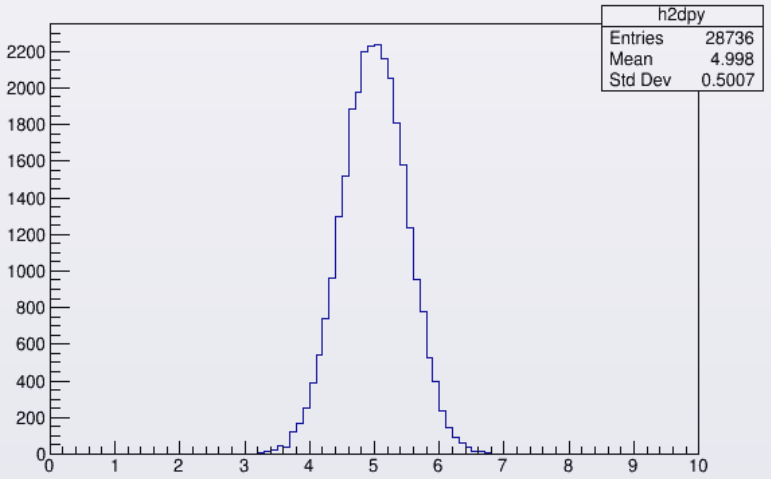
On the canvas, position your mouse inside the histogram. Rt Click + select `SetShowProjectionX`.
Still on the 2D histogram, slide your mouse up/down. In a separate window you'll see the projections ☺

- How to get a projection as an object of TH1_ class :

```
root[8] h2d.ProjectionX ( "h2dpx", ay->FindBin(4.5) , ay->FindBin(5.5) )
h2dpx(class TH1D *) 0x3660560
root[9] h2dpx->Draw()
```




```
root[10] h2d.ProjectionY ( "h2dpy", ax->FindBin(2.5) , ax->FindBin(3.5) )
root[11] h2dpy->Draw()
```



Basic graphics

- Points/Markers (`TMarker`), Lines (`TLine`), Arrows (`TArrow`)
- Boxes (`TBox`), Circles/Ellipses (`TEllipse`)
- Inscriptions (`TText`), also in the LaTeX style (`TLatex`)

Exemplary help

→ `Manual:` Graphics chapter
→ `User guide:` Graphics chapter

Basic objects

[1] **TLine** (Lines)

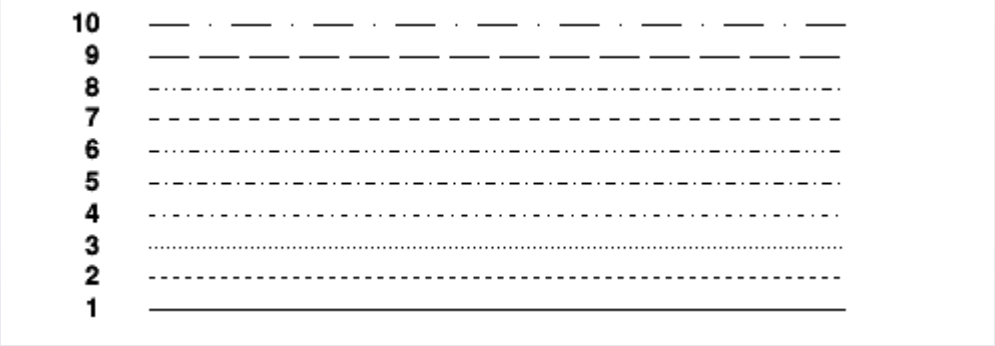
```
root[1] TH2F h2d ("h2d", "My Histo", 10, 0., 10., 10, 0., 10.); h2d.Draw()
root[2] TLine l1 (0., 0., 1., 1.) ; l1.Draw ()
root[3] TLine l2 (0., 0., 1., 1.) ; l2.SetNDC (kTRUE) ; l2.Draw("same")
```

NDC (Normalized Device Coordinates) : `SetNDC (0)` → Coordinates according to actual plot
`SetNDC (1)` → as fractions of window dimensions

```
root[4] l2.SetLineColor (2); l2.SetLineStyle (2); l2.SetLineWidth (3)
```



Color numbering scheme in generic palette

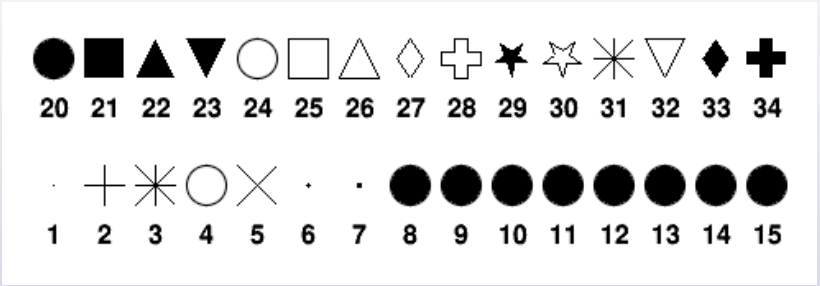


Numbering of line styles

Basic objects

[2] TMarker (Points / markers)

```
root[1] TMarker m (3., 8., 31)
root[2] m.SetMarkerColor (4);
root[3] m.SetMarkerSize (2.0);
root[4] m.Draw()
```



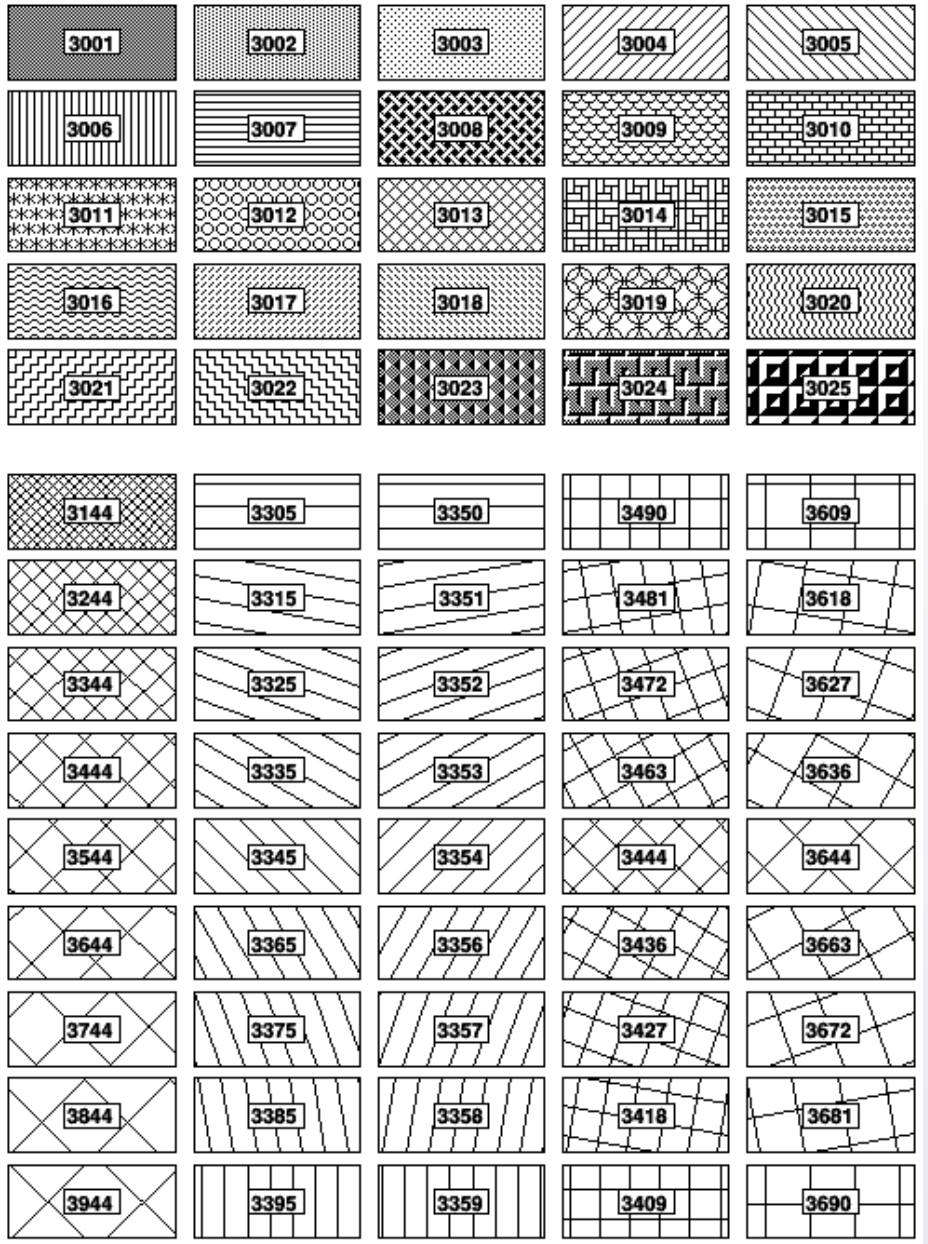
Numbering scheme of markers

[3] TBox (Rectangles)

```
root[1] TBox b (5., 2., 8., 3.);
root[2] b.SetLine……..
root[3] b.SetFillColor (4)
root[4] b.SetFillStyle (3014);
```

Conventions of defining the filling style:

root.cern/doc/master/classTAttFill.html#ATTFILL2



Numbering scheme of some hatch styles

Basic graphics, cont.

[4] TEllipse (Circles / ellipses)

```
root[1] TEllipse e (
```



```
TEllipse TEllipse (Double_t x1, Double_t y1,
 Double_t r1, Double_t r2 = 0,
 Double_t phimin = 0, Double_t phimax = 360,
 Double_t theta = 0)
```

Range of angles of ellipse fragment : [PhiMin, PhiMax]
Angle of figure rotation : Theta

E.g.:

```
root[1] TEllipse e (5, 5, 4, 2, 0, 270, 45)
```

Line and filling – specific attributes work here.

[5] TText (Basic text)

```
root[1] TText t (0.5, 0.5, "Hello World!");
root[2] t.SetTextColor (2)
root[3] t.SetTextFont (43)
root[4] t.SetTextSize (40)
root[5] t.SetTextAngle(45)
root[6] t.Draw()
```

- Numbering scheme of font styles.
  Units digit = degree of **precision**

12 : *ABCDEFGH abcdefgh 0123456789 @#$*

22 : **ABCDEFGH abcdefgh 0123456789 @#$**

32 : ***ABCDEFGH abcdefgh 0123456789 @#$***

42 : ABCDEFGH abcdefgh 0123456789 @#$

52 : *ABCDEFGH abcdefgh 0123456789 @#$*

62 : **ABCDEFGH abcdefgh 0123456789 @#$**

72 : ***ABCDEFGH abcdefgh 0123456789 @#$***

82 : ABCDEFGH abcdefgh 0123456789 @#$

92 : *ABCDEFGH abcdefgh 0123456789 @#$*

102 : **ABCDEFGH abcdefgh 0123456789 @#$**

112 : ***ABCDEFGH abcdefgh 0123456789 @#$***

122 : ΑΒΧΔΕΦΓΗ αβχδεφγη 0123456789 ≅#∃

132 : ABCDEFGH abcdefgh 0123456789 @#$

142 : 

152 : *ΑΒΧΔΕΦΓΗ αβχδεφγη 0123456789 ≅#∃*

Basic graphics, cont.

[6] **TLatex** (advanced text: mathematical expressions, etc.)

Helpful summary: root.cern/doc/master/classTLatex.html

```
root[1] TLatex l;
root[2] l.SetNDC (1);
root[3] l.SetTextSize (0.06);
root[4] l.SetTextAngle (45.);
root[5] l.SetTextColor (4);
root[6] l.DrawLatex (0.5, 0.6, "E^{2} = m^{2} + p^{2}")
```

← A single object acts as a text processor

- A few basic rules:

`^{…}`	: top index	`#frac{Numerator}{Denom.}`	: Horizontal fraction
`_{…}`	: bottom intex	`#sqrt{x}  ,  #sqrt{N}{x}`	: root of degree 2 and higher
`#bf{…}`	: bold font	`#splitline{Above}{Below}`	: two lines, one above the other
`#it{…}`	: italic font	`#color[4]{Blue}`	: local change of color
`#vec{…}`	: vector	`#font[12]{Font}`	: local change of font size
`#(){…}`	: large brackets	`#scale[1.2]{Larger}`	: local rescaling of font size

```
root[7] l.DrawLatex (0.5,0.6,"#gamma_{cm} = #frac{1}{#sqrt{1-#beta^{2}_{cm}}}")
```

- Some examples from the ROOT site:

{}^{40}_{20}Ca : $^{40}_{20}Ca$

x = #frac{y+z/2}{y^{2}+1} : $x = \frac{y+z/2}{y^2+1}$

Basic graphics, cont.

[6] **TLatex** class, cont.

Codes for Greek symbols (preceded by #)

Lower case		Upper case		Variations	
alpha :	α	Alpha :	A		
beta :	β	Beta :	B		
gamma :	γ	Gamma :	Γ		
delta :	δ	Delta :	Δ		
epsilon :	ϵ	Epsilon :	E	varepsilon :	ε
zeta :	ζ	Zeta :	Z		
eta :	η	Eta :	H		
theta :	θ	Theta :	Θ	vartheta :	ϑ
iota :	ι	Iota :	I		
kappa :	κ	Kappa :	K		
lambda :	λ	Lambda :	Λ		
mu :	μ	Mu :	M		
nu :	ν	Nu :	N		
xi :	ξ	Xi :	Ξ		
omicron :	ο	Omicron :	O		
pi :	π	Pi :	Π		
rho :	ρ	Rho :	P		
sigma :	σ	Sigma :	Σ	varsigma :	ς
tau :	τ	Tau :	T		
upsilon :	υ	Upsilon :	Υ	varUpsilon :	ϒ
phi :	ϕ	Phi :	Φ	varphi :	φ
chi :	χ	Chi :	X		
psi :	ψ	Psi :	Ψ		
omega :	ω	Omega :	Ω	varomega :	ϖ

Upper diacritic signs:

#tilde :	ã
#ddot :	ä
#dot :	ȧ
#grave :	à
#acute :	á
#check :	ǎ
#hat :	â
#bar{a} :	$\bar{a}$
#vec{a} :	$\vec{a}$

Basic graphics, cont.

[6] **TLatex** class, cont.

Mathematical and other special symbols

♣	#club	⇔	#Leftrightarrow	←	#leftarrow	∇	#nabla	å	#aa
℘	#voidn	|	#void8	⊗	#otimes	↵	#downleftarrow	⁄	#/
≤	#leq	ℏ	#hbar	⇐	#Leftarrow	—	#topbar	\	#backslash
≈	#approx	♦	#diamond	∏	#prod	⌠	#arcbar	·	#upoint
∈	#in	ℵ	#aleph	□	#Box	↑	#uparrow	∂	#partial
⊃	#supset	≥	#geq	||	#parallel	⊕	#oplus	¬	#corner
∩	#cap	≠	#neq	♥	#heart	⇑	#Uparrow	⌡	#lbar
©	#ocopyright	∉	#notin	ℑ	#Jgothic	∑	#sum	⌊	#bottombar
™	#trademark	⊆	#subseteq	⟨	#LT	⊥	#perp	→	#rightarrow
×	#times	∪	#cup	≡	#equiv	∀	#forall	√	#surd
•	#bullet	℗	#copyright	⊂	#subset	♠	#spade	⇒	#Rightarrow
ƒ	#voidb	™	#void3	⊇	#supseteq	ℜ	#Rgothic	∫	#int
″	#doublequote	÷	#divide	∧	#wedge	⟩	#GT	⊙	#odot
|	#lbar	°	#circ	®	#oright	∝	#propto	∃	#exists
⌈	#arcbottom	∞	#infty	Å	#AA	⊄	#notsubset	+	#plus
↓	#downarrow	∠	#angle	±	#pm	∅	#oslash	−	#minus
↔	#leftrightarrow	|	#cbar	∓	#mp	∨	#vee		
⇓	#Downarrow	⌠	#arctop	…	#3dots	®	#void1		

TPad graphical area placed in a subregion of TCanvas (or another TPad)

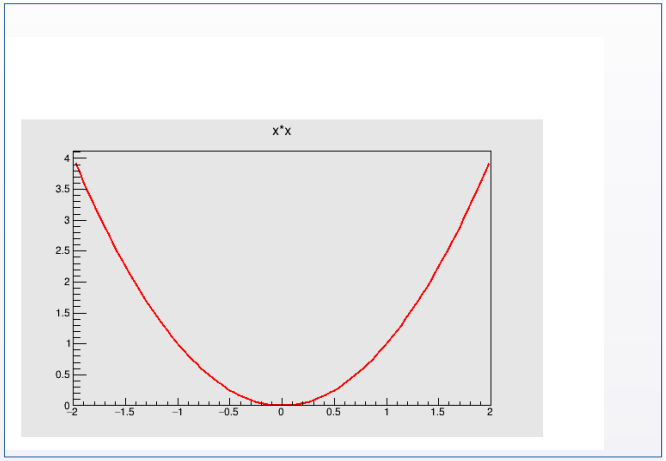
Let's try it out:

```
root[0] TCanvas c1;
root[1] TPad p1 ("p1", "", 0.0, 0.0, 0.7, 0.6, 18);
```

Range coordinates
- order: [x_{Low}, y_{Low}] [x_{Up}, y_{Up}]
- given in NDC units.

pad colour (default: white)

```
root[2] p1.Draw ();
root[3] p1.cd();
root[4] TF1 fun ("fun", "x*x", -2, 2);
root[5] fun.Draw();
```



We can also divide the TCanvas automatically into matrix of TPad's:

```
root[6] c1.Divide ( Ncols , Nrows )
root[7] c1.ls()
```

We can see that:
- the created TPads "belong" to c1,
- they were automatically given names: c1_1, c1_2, ...

To activate one TPad belonging to a given TCanvas , we call it by its number:

```
root[8] c1->cd ( [1 .. Nc × Nr] );
```

Caution: Changing back to c1 and drawing something there – deletes all the above TPads.

- We always have at disposal the **pointer to the active window**: **gPad**

```
root[9] gPad->Print ("tpad_plot.gif");
```

TStyle Object managing the graphical style

In ROOT session, the **gStyle** object of **TStyle** class is available. It keeps settings of graphics style. The settings concern e.g. the attributes of canvas, lines, markers, stats.
Access is through the getters and setters.

```
root[0] gStyle->Set
```



```
root[0] gStyle->SetLabelSize    (0.07, "XY");
root[1] gStyle->SetLabelOffset (0.01, "Y" );
root[2] gStyle->SetNdivisions   ( 2   , "X" );
root[3] TH1F h1 ("h1", "", 10, -5, 5);
root[4] h1.Draw ();
```

However, if we first define a histogram, and change the style later on, we need to tell this histogram to update the style:

```
root[5] gStyle->SetNdivisions ( 8 , "X" );
root[6] h1.Draw ();
root[7] h1.UseCurrentStyle ();
root[8] h1.Draw ();
```

Important: TStyle allows to modify the contents of displayed statistics:

```
root[9] gStyle->SetOptStat ( {rmen} );
```

Symbols **{r m e n}** are the basic 4 of 9 attributes to display. They can take values {0, 1} , sometimes 2.

Basic properties:

```
r = (0) 1:   (do not) display RMS
m = (0) 1:   (do not) display the mean
e = (0) 1:   (do not) display the count numbers
n = (0) 1:   (do not) display the histogram name
```

Link to the full list.

TFile communication with files in .root format (root.cern/root/htmldoc/guides/users-guide/InputOutput.html root.cern/doc/master/classTFile.html)

ROOT's native format allows to store every object of class recognized by ROOT.
It should be then retrievable as an object.

Let's first learn the basics.

We'll create the .root file, put some histogram there and close this file.

```
root[0] TFile f ("myfile.root", "RECREATE");
root[1] TH1F  h ("myhisto", "My Histo's Title", 10, -5., 5.);
root[2] TRandom3 r;  for (int i = 0 ; i < 1e5 ; i++)  h.Fill ( r.Gaus() );
root[3] h.Write ();                                    ← Writing object to file
root[4] f.Close ();
root[5] .! ls -og myfile.root
```

Let's leave and reenter ROOT. Now, we'll open the written file for reading, extract the histo and draw it.

```
root[0] TFile f ("myfile.root", "READ");          ← Opening file for reading
root[1] f.ls();                                   ← Listing file's content
root[2] TH1F* hread = (TH1F*) f.Get ("myhisto");
```

It's important to understand the command above. `TFile::Get` extracts from the file – the address of the required object, but returns it in the `TObject*` type (*nearly* the base class of all ROOT objs). It is on our shoulders to cast it onto the relevant type (here, `TH1F*`).

An alternative way to extract a histo:

```
root[3] TH1F* hread2 = f.Get<TH1F> ("myhisto");


root[4] hread->Draw ();
root[5] f.Close ();
```

TFile (cont.)

Let's have a closer look and first check if a given file exists:

```
root[0] cout << gSystem->AccessPathName ("myfile.root");
false                                          ← false if file exists
```

The .root file can be open in different modes, depending if you want to only read, or write (and how) :

```
root[1] TFile f ("myfile.root", "RECREATE");
```

options: "NEW" "RECREATE" "UPDATE" "READ"

You may want to check if the file was opened successfully:

```
root[2] if (f.IsOpen () == true) cout << "File open.\n";
```

Now let's see the file length and print out its table of contents:

```
Root[3] .! ls -og myfile.root
root[4] f.ls();
```

Okay. Now we're going to create some histogram:

```
root[5] TH1F h ("h", "myhisto", 10, 0., 10.);
root[6] f.ls();                                ← h linked, but not saved yet.
root[7] .! ls -og myfile.root
```

Hm, despite size didn't change, `myhisto` is listed. We'll explain it later. Let's store `myhisto` in the file:

```
root[8] h.Write ();
root[9] .! ls -og myfile.root
root[10] f.ls();                               ← h linked and saved.
```

Now, file size increased and `myhisto` has a "KEY".
Nb. while writing, we can also give the object another name inside that file. Finally, let's close the file.

```
root[11] h.Write ("h_copy");
root[12] f.ls ();                              ← h written under the new name
root[13] f.Close();
```

I/O cont.

- ROOT session with file connection:

```
$ root -l myfile.root
root[0]
Attaching file myfile.root as _file0...
(class TFile *) 0x1943c70
root[1] _file0->ls();
```

← Pointer to object of `TFile` class

- Setting up the work directory on a disk:

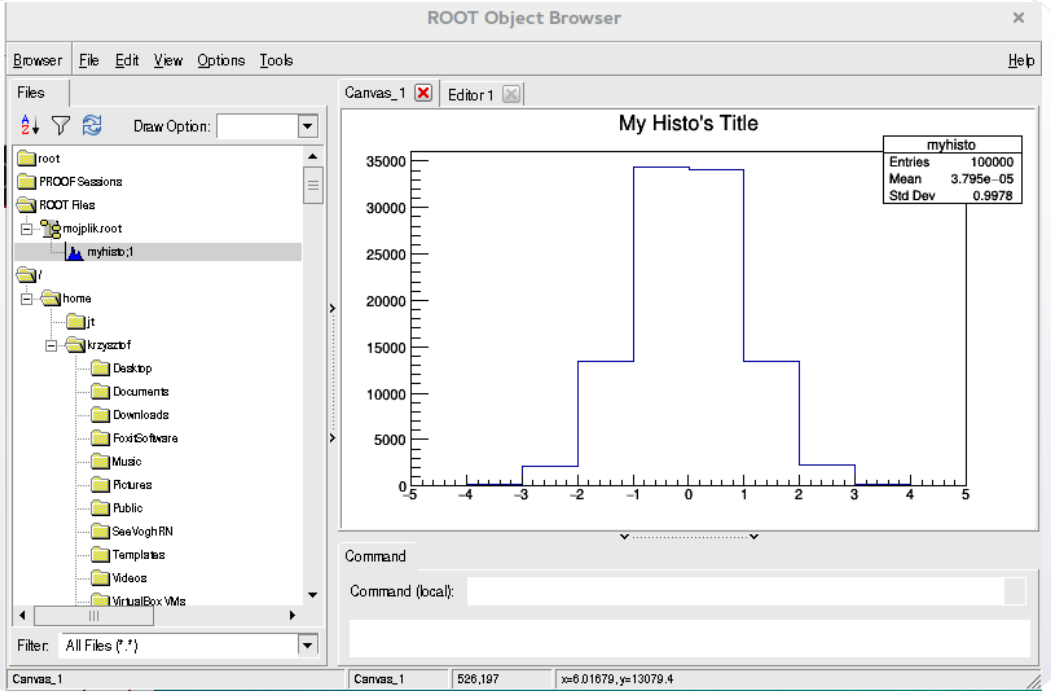
```
root[2] gSystem->pwd ()
(const char *) "/home/krzysztof/didact/informatyka/nuctools"
root[3] gSystem->cd ("../")
root[4] gSystem->pwd()
(const char *) "/home/krzysztof/didact/informatyka/"
```

- **TBrowser**: the object-oriented browser

```
root[5] new TBrowser
```

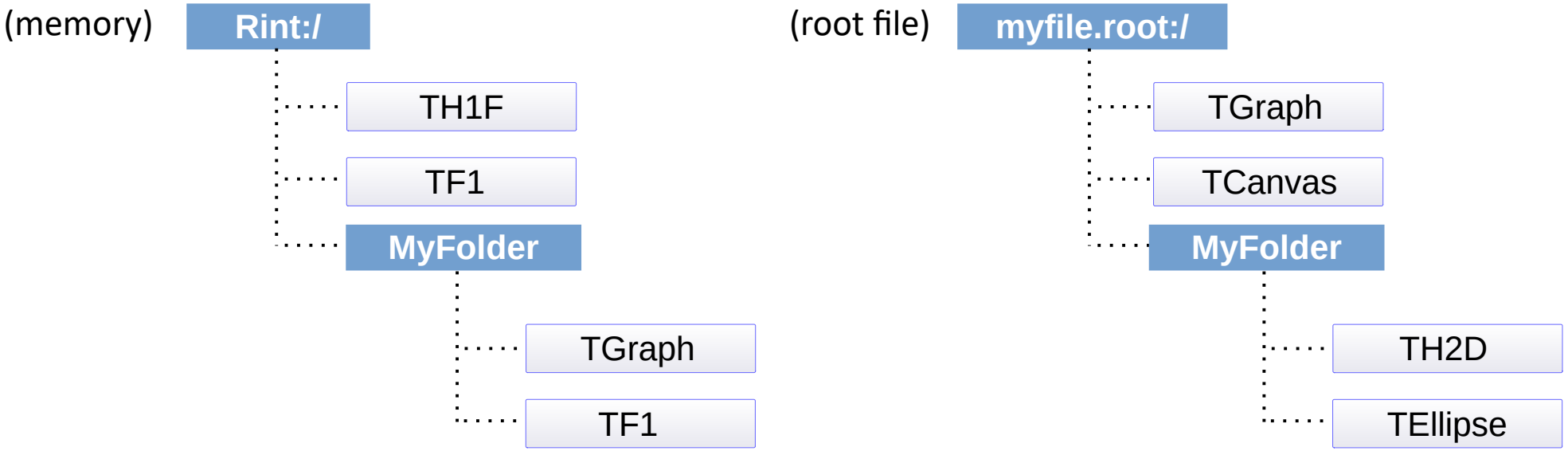
In some Root versions the TBrowser will appear as embedded in the web browser.
You may like it or not.
If you want to prevent it, launch Root this way:

```
$ root --web=off
```



gDirectory Hierarchy of objects in Root files and memory

- ROOT maintains a **structure of directories** (in memory, as well as inside .root files) .




```
$ root -l
root[0] gDirectory->pwd ()      or      .pwd
Current directory: Rint:/                          ← Main directory in memory

root[1] TFile f1 ("myfile.root"); cout << gDirectory->GetPath () << endl;
Myfile.root:/

root[2] gDirectory->ls ()       or      .ls
TFile**         myfile.root                        ← We see we've moved to a file
 TFile*         myfile.root
  KEY: TH1F     h;1     myhisto
```

gDirectory Hierarchy of objects in Root files and memory

Creating subdirectories (in memory or inside a `.root` file)

```
root[3] TFile f2 ("newfile.root", "RECREATE")
root[4] gDirectory->mkdir ("folder1");                    <-- New directory in file
root[5] gDirectory->cd ("folder1");
root[6] gDirectory->pwd ()
newfile.root:/folder1                                     <-- myhisto saved in folder1

root[7] TH1F h ("myhisto", "", 10, -5., 5);  h.Write();
root[8] .ls
TDirectoryFile*         folder1     folder1
 OBJ: TH1F      myhisto  : 0 at: 0x7f06ee3ce000
 KEY: TH1F      myhisto;1

root[8] gDirectory->cd ("..") ;                           <-- Back to main folder in file
root[9] gDirectory->rmdir ("folder1")
root[10] f2.Close ();

root[11] cout << gDirectory->GetPath() << endl;
Rint:/

root[12] f1.cd() ; gDirectory->pwd();                     <-- cd() as method of TFile
Myfile.root:/

root[13] gDirectory->cd ("Rint:/") ;                      <-- way to get back to memory
root[14] gDirectory->pwd();
Rint:/
```

MACROS : C++/ROOT codes in a file

Handy mode: macro_noname.C

```
{
  TH1F h1 ("hist1", "", 50, -5., 5.);
  TH1F* h2 = new TH1F
           ("hist2", "", 50, -5., 5.);

  TRandom3 r;  r.SetSeed ();

  for (int i=0 ; i<1e5 ; i++) {
    h1.Fill  ( r.Gaus() );
    h2->Fill ( r.Gaus() );
  }
  h1.Draw();
}
```

After execution, in an interactive session:

- Exists: `h1` (object) and `h2` (pointer)
- One can call: `h1, h2, hist1, hist2`

Full mode (functions):

Name the same as filename

```
int macro_function () {
  TH1F h1 ("hist1", "", 50, -5., 5.);
  TH1F* h2 = new TH1F
           ("hist2", "", 50, -5., 5.);

  TRandom3 r;  r.SetSeed ();

  for (int i=0 ; i<1e5 ; i++) {
    h1.Fill  ( r.Gaus() );
    h2->Fill ( r.Gaus() );
  }

//TCanvas can1 ("c1", "", 640, 480);

  h1.Draw();

//can1.Update();
//cin.ignore();

  return 0;
}
```

After execution, in an interactive session:

- `h1` (object) not present (also via `hist1`)
- one cannot call `h2`
- possible to call `hist2`

Additional commands needed to capture graphics

MACROS cont.

- **Input arguments of function:**

```
double macro_inputarg (double x = 0)
{
  cout << "Hello world! " << x << endl;
  return x;
}
```

```
$ root -b "macro_inputarg.C(12.34)"
```

← No space between .C and (...)

- **Calling from session:**

```
root[0] .x macro_inputarg.C(-12.)
```

- A macro can contain more functions.
- The starting function (equivalent of `main`) MUST have the same name as a filename

```
Double_t W (Double_t x) {
  return 3*pow(x,2) - 1.5*x + 4.;
}

int macro_giveW (double x) {
  cout << "W(x) = " << W(x) << endl;
  return 0;
}
```

- A macro can be loaded first and run later:

```
root[0] .L macro_inputarg.C
root[1] macro_inputarg (123) ;
Hello world! 123
```

← This way you can quickly check the integrity of C++ code.

- **One can compile the macro in the session.** But the code must contain `#include< … >`

```
root[0] .L macro_inputarg.C+
root[1] macro_inputarg (-123.45);
```

← Will create file `macro_inputarg_C.so`

MACROS cont. Some goodies:

- You can include some macro `A.C` into yours, and further use its functions by simply:

```
#include "A.C"
```

- You can also achieve this, also interactively, by:

```
gROOT->LoadMacro ("A.C");
```

- ... and then execute a given function by:

```
gROOT->ProcessLine (" myFunction() ")
```

- You can also execute the whole macro (while sitting inside your macro)

```
gROOT->Macro ("A.C")
```

- Also, you can execute a Linux command:

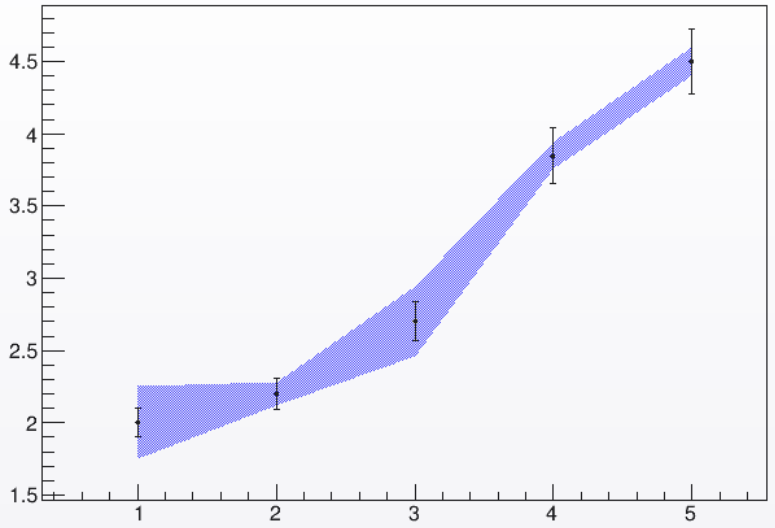
```
root[0] gSystem->Exec ("date")
Tue, Nov 5, 09:55:01 CET
```

- and if a Linux command prints something out, you can retrieve it with:

```
root[5] TString datenow = gSystem->GetFromPipe ("date")
```

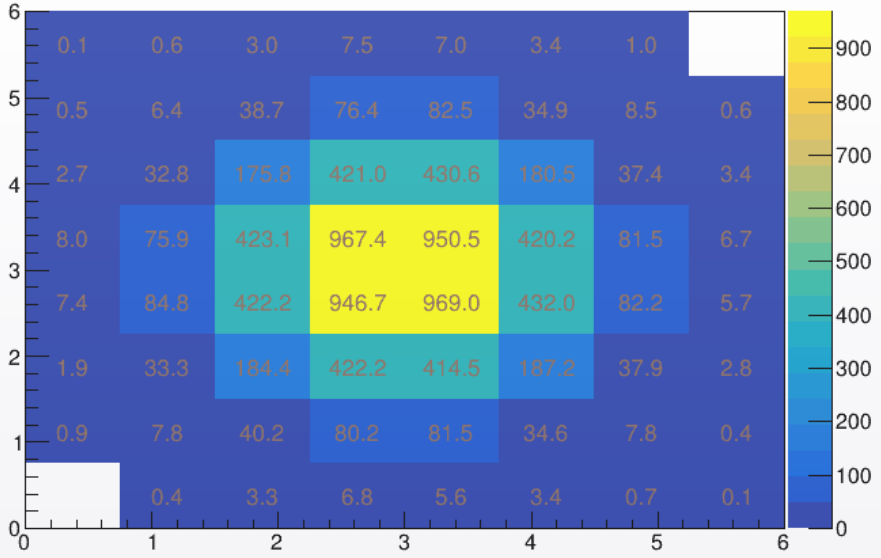
- **Some extra plotting features, coding stored in macros**

Bands (corridors) within top and low errors



```
int point_corridor () {
 Float_t X [] = { 1   ,  2   ,  3   ,  4   ,  5  } ,
         Y1[] = {1.75, 2.12, 2.46, 3.75, 4.40} ,
         Y2[] = {2.25, 2.28, 2.95, 3.94, 4.60} ;
 TGraphErrors* gSys = new TGraphErrors (5) ,
             * gSta = new TGraphErrors (5) ;
 for (int i = 0; i < 5; i++) {
  gSta->SetPoint (i, X[i], (Y1[i] + Y2[i])/2 );
  gSys->SetPoint (i, X[i], (Y1[i] + Y2[i])/2 );
  gSta->SetPointError (i, 0, 0.05*(Y1[i]+Y2[i])/2.);
  gSys->SetPointError (i, (Y2[i]-Y1[i])/2. ,
                          (Y2[i]-Y1[i])/2.) ;
 }
 gSys->SetTitle ("");
 gSys->SetFillColor (kBlue-4);
 gSys->SetFillStyle (3001);
 gSys->Draw ("APE3");
 gSta->SetMarkerColor (kBlack);
 gSta->SetMarkerStyle (20);
 gSta->SetMarkerSize  (0.5);
 gSta->Draw ("Psame");
}
```

Showing cell heights as values




```
int text_inhisto () {
  gStyle->SetPaintTextFormat (".1f");
  gStyle->SetTextFont (42);
  TRandom3 r;
  TH2F* h = new TH2F ("h","",8,0,6,8,0,6);
  h->SetStats (0.);
  for (int i = 0; i <9e4; i++)
    h->Fill ( r.Gaus(3., 0.8) ,
              r.Gaus(3., 0.8) , 0.1 );

  h->SetMarkerSize (1.9) ;
  h->SetMarkerColor (28) ;
  h->Draw ("colz text");
  return 0;
}
```

TLegend Legend for a plot

Each plot can be accompanied with a legend (one or more).
An object of **TLegend** class needs to be linked with the plotted: functions, histograms or graphs.
We decide, what inscription and symbol we assign (line, marker, rectangle, point with uncertainty).

```
int macro_TLegend() {
 TH1F* h = new TH1F ("h", "Example", 200, -14, 10);
 h->FillRandom ("gaus", 30000);
 h->SetFillColor (18);
 h->Draw ();

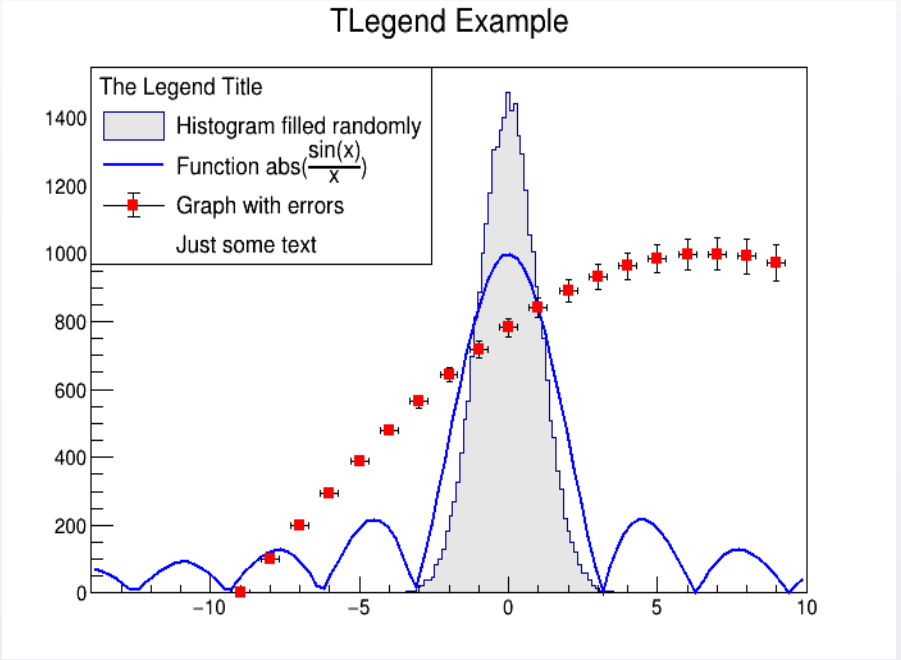
 TF1* f= new TF1("f", "1000*abs(sin(x)/x)",-14,14);
 f->SetLineColor (kBlue);
 f->Draw ("same");

 Int_t i = 0;
 Double_t x[50], y[50], ex[50], ey[50];
 for (Double_t xval = -9; xval <= 9; xval++, i++){
   x[i]  = xval;
   y[i]  = 1000 * sin ( (xval + 9)/10 ) ;
   ex[i] = 0.3;
   ey[i] = (xval+9) * 3 ;
 }
 TGraphErrors* gr = new TGraphErrors (i,x,y,ex,ey);
 gr->SetName ("gr");
 gr->SetMarkerStyle (21);
 gr->SetMarkerColor (kRed);
 gr->Draw ("P");

 TLegend* leg = new TLegend (0.1, 0.6, 0.48, 0.9);
 leg->SetHeader ("The Legend Title");
 leg->AddEntry ( h  , "Histogram filled rand", "f");
 leg->AddEntry ("f" , "abs(#frac{sin(x)}{x})", "l");
 leg->AddEntry ("gr", "Graph with errors"  , "lep");
 leg->AddEntry ((TObject*)0, "Just some text",  "");
 leg->Draw ();
 return 0;
}
```

Legend must be displayed by command

This macro draws histogram, function and TGraph.
Next, it creates the legend for them
and modifies the symbols' attributes in the legend.



Creating legend within certain canvas area

Legend's title

Entries corresponding to objects.
Options: f = filled box, l = line
p = marker e = error bar

In case if text only

Good plot in ROOT. This macro is a proposition of the way of creating a readable and clear plot.

```
int macro_GoodPlotExample () {
  gStyle->SetOptStat (0);
  gStyle->SetLegendBorderSize (0);
  gStyle->SetLegendTextSize   (0.055);
  gStyle->SetLabelSize  (0.055, "XY");
  gStyle->SetNdivisions ( 505 , "XY");
  gStyle->SetTextFont (42);

{… creation of histogram, curve and TGraphErrors …}

  h1->GetXaxis()->SetTitle ("Position (#mum)");
  h1->GetXaxis()->CenterTitle (true);
  h1->GetXaxis()->SetTitleOffset (1.25);
  h1->GetXaxis()->SetTitleSize(0.055);
{… same for Y axis …}

  TCanvas* c1 = new TCanvas ("c1", "", 800, 600);
  c1->SetGrid (0, 0);
  c1->SetTopMargin    (0.05);
  c1->SetBottomMargin (0.15);
  c1->SetRightMargin  (0.04);
  c1->SetLeftMargin   (0.16);

  h1->Draw ();
  f1->Draw ("same");
  gr->Draw ("P");

  TLegend* leg = new TLegend
           (0.21, 0.63, 0.5, 0.86, "", "nbNDC");
  leg->AddEntry ( h1 , "   Experiment" , "f"  );
  leg->AddEntry ("f1", "   Model"      , "l"  );
  leg->AddEntry ("gr", "   Efficiency" , "lep");
  leg->Draw ();

  TLatex l;
  l.SetNDC (1);
  l.SetTextSize (0.055);
  l.SetTextFont (42);
  l.DrawLatex (0.82, 0.845, "(A)" );
}
```

Style settings

Do not plot stats
Legend: no frame
Legend: font size
Font size of axis values
Number of divisions of X and Y axis
Set font to Helvetica and precision 2

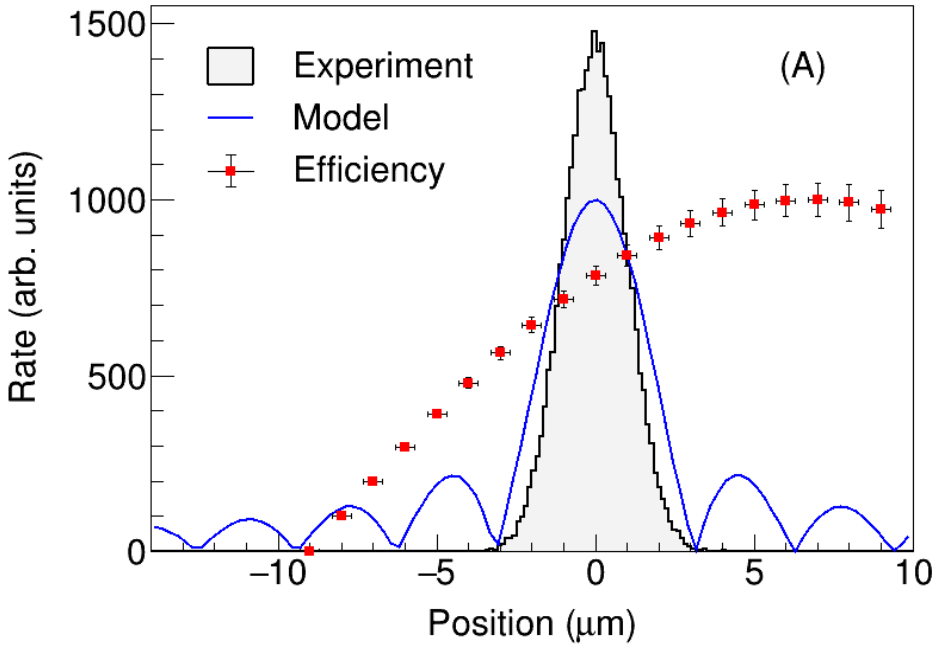
Axis Title

Margins

Legend

Text overlay

Use coordinates of TCanvas
Font size
Font style: Helvetica, precision: 2
Print the text



MACROS : C++ functions used by TFn objects

Through "Inline Expression" :

```
Double_t W (Double_t x) {
  return pow(x,3) - 6.*pow(x,2)
         + x - 1.;
}

int macro_funcInline ()
{
  TCanvas c1 ("c1", "", 640, 480);
  TF1 f1 ("f1", "W(x)", -10., 10.);
  f1.Draw();
  c1.Update();
  cin.ignore();
  return 0;
}
```

Through function with parameters:

```
Double_t myFun (Double_t *xarg,
                Double_t *par)
{
  Double_t x = xarg[0] , result = 0.;

  for (int deg = 0 ; deg <= 3 ; deg++)
    result += par[deg]
              * TMath::Power (x, deg);
  return result;
}

int macro_funcFunc ()
{
  TCanvas c1 ("c1", "", 640, 480);
  TF1 f1 ("myfun1", myFun, -3, 5, 4);
  f1.SetParameters (-1., 1., -6., 1.);
  f1.Draw();
  c1.Update();
  cin.ignore();
  return 0;
}
```

Notice:

in myFun we can encode anything
e.g. if/else blocks or calls to other functions

Fitting of function to data points

Please download the test data: `wget www.fuw.edu.pl/~kpias/ctnp/dataPoints.txt`

```
void macro_FitTGraphErrors () {
 TCanvas* c1 = new TCanvas ("c1");
 TGraphErrors gr ("dataPoints.txt");
 gr.SetTitle ();
 gr.Draw("AP");

 TF1 fun ("fun", myFun , -3, 5, 4);
 fun.SetParameters (-1. , 1. , -6. , 1.);
 gr.Fit ( &fun );

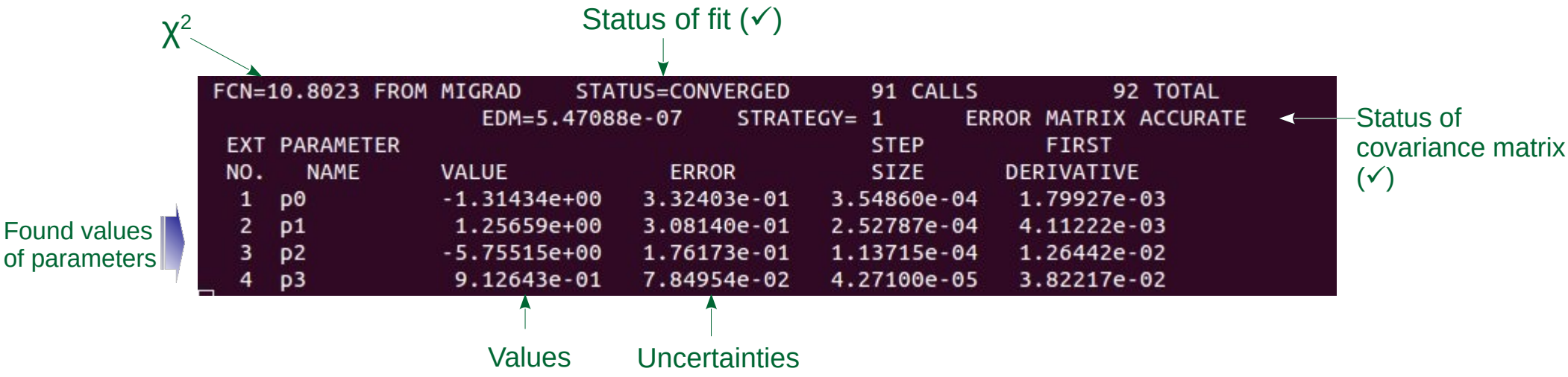
 c1->Update();
 cin.ignore();
}
```

Graph with experimental data

Model function (with parameters - !)

Fit command. MINUIT package (from CERN)

Exemplary result of (successful) fit:



Fitting of function to data points cont.

Setting up the initial parameters:

```
fun1.SetParameter  (index, value) ;
fun1.SetParameters (value, value, … , value);
fun1.FixParameter  (index, value) ;

fun1.SetParLimits  (index, min, max) ;
gr.Fit ( &fun , "" );
```

← Set parameter's value
← Set all the parameters
← Fix a given parameter

← Set the fitting range

Getting the values of found parameters:

```
fun1.GetParameter (index) ;
fun1.GetParError  (index) ;
fun1.GetChisquare ();
fun1.GetNDF ();
```

← Get parameter's value
← Get parameter's error
← Get χ^2 value
← Get number of d.o.f.

Usage of **built-in (predefined) functions** [full list **here**]

```
gr.Fit ( "pol3" );
```

`polN`	`f(x) = p0 + p1*x + p2*x2 + …`
`expo`	`f(x) = exp (p0 + p1*x)`
`gaus`	`f(x) = p0*exp (-0.5 * [(x-p1) / p2]^2)`
`gausn`	(Normal Distribution)
`crystalball`	(*Crystal Ball* "Gaussian with tail at low-X")
`breitwigner`	(*Breit-Wigner* distribution of particle's mass)
`landau`	(*Landau* distribution of energy losses)
`chebN`	(*Chebyshev* polynomial of degree N)

Caution: for a *predefined* function, if we narrow down the range of parameters (or fix some value(s)), we have to add `"B"` into the option of `Fit` method.

Fitting of function to data points cont.

- The **`Fit`** method works also for histograms, including 2, 3 – dimensional ones. Full form of method:

```
TFitResultPtr Fit (TF1* f1, Option_t* option = "" ,        ← Fitting options
                           Option_t* goption = "" ,        ← Drawing options
                   Double_t xmin = 0, Double_t xmax = 0)   ← Range on X axis
```

- **Fitting options** (selection of more practical ones; for details see *this link*)

only for histograms (`THdf`) :

`I`	`(Integral)`	Average the function over each bin (for strongly changing functions)
`L`	`(LogLikelihood)`	Use the Log Likelihood method (instead of χ^2).

For histograms and graphs (`TGraph_____`) :

`M`	`(iMprove)`	Obtain the more precise fit results
`E`	`(Error)`	Obtain uncertainties more exactly with help of Minuit's MINOS package.
`B`	`(Bound)`	For predefined functions: if range of parameter values is limited
`R`	`(Range)`	Fit in range, in which the function is defined
`0`		Do not plot the fitted function
`V`	`(Verbose)`	Verbose mode
`Q`	`(Quiet)`	Quiet mode

- In case of fitting the 2 (3) – dimensional function to the 2 (3) – dimensional data:
  - The fitting range should be specified in the constructor of the TFn object
  - Add `"R"` to the fitting options of the `Fit` method.
  - If you specify `xmin` and/or `xmax` in arguments of `Fit` method, these values work only for X axis

Fitting of function to data points cont.

- Extraction of **covariance matrix** (*goal: linear correlations between fitted parameters*)

```
void macro_FitErrorMatrix () {
 TCanvas* c1 = new TCanvas ("c1");
 TGraphErrors* gr = new TGraphErrors("dataPoints.txt");
 gr->SetTitle ();
 gr->Draw("AP");

 TF1* fun = new TF1 ("fun", myFun , -3, 5, 4);
 fun->SetParameters (-1. , 1. , -6. , 1.);

 TFitResultPtr fitRes = gr->Fit ( &fun , "S" );
 TMatrixDSym cov = fitRes->GetCovarianceMatrix();

 for (int r = 0; r < cov.GetNrows () ; r++) {
  for (int c = 0; c < cov.GetNcols() ; c++)
   cout << setw(16) << cov[r][c] ;

  cout << endl;
 }

 c1->Update();
 cin.ignore();
}
```

`TFitResultPtr` stores the fit results

`GetCovariance...` returns the covariance matrix

`TMatrixDsym` symmetric matrix of *double* elements

- To access the **fit status** inside the code (*string*)

```
#include "TMinuit.h"
string myFitStatus = gMinuit->fCstatu ;
```

At the beginning of the code

Getting the status (*string*)

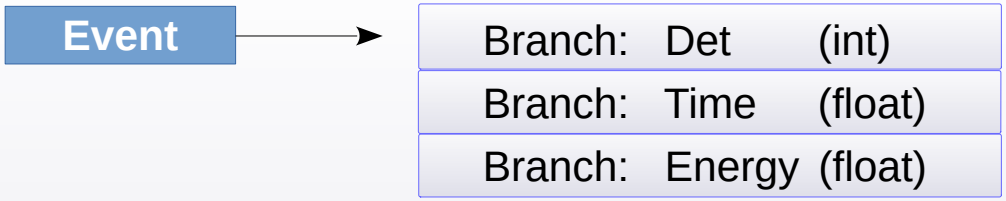
TTree Trees (data bases)

Eg. experiment measuring particles in detectors: i-th particle with $\{N_i\ T_i\ E_i\}$ from a detector (detectors)
Eg. experiment measuring tracks of particles in drift chambers : set of p_x, p_y, p_z, ΔE_i from a chamber

A simple data scheme



Possible data structures for description of an event within ROOT Tree:



(easier)



(more advanced)

Let's first look at variant 1.

TTree Simplest way to create a tree from data in a text file

① Download data. They are in 3 columns (int, float, float)

```
wget www.fuw.edu.pl/~kpias/ctnp/MyExpData.txt
```

```
11      16.832    10.8703
11     20.4335    8.65938
 7    0.634218    8.03354
 1     21.3472    19.6014
...
```

② Open the TTree object and fill the database with data using the **ReadFile** method:

Declaration of tree

ReadFile fills the tree from txt file

Print displays stats

Scan prints out data

Draw : en-time plot
We set up filter on det

Write saves tree in file

```
int TTree_ReadFile ()
{
  TFile f ( "simplest_tree.root", "RECREATE" );
  TTree t ( "mytree" , "Tree of data for my analysis" );
  t.ReadFile ("MyExpData.txt", "det/I:energy/F:time/F" );
  t.Print ();
  t.Scan ( "det:energy:time" );
  t.Draw ( "energy:time" , "det >= 7" );
  t.Write ();
  return 0;
}
```

TTree cont.

Now we'll design the tree by ourselves.

- **Scheme "1 branch = 1 variable"**

Define the branch:

```
t.Branch ("Name"  ,
          &variable,
          "variable/F");
```

Encoding the variable size:

F	: float	, 4 bytes
D	: double	, 8 bytes
I	: signed integer	, 4 bytes
i	: unsigned integer	, 4 bytes
C	: c-string	
B	: signed integer	, 1 byte
b	: unsigned integer	, 1 byte
S	: signed integer	, 2 bytes
s	: unsigned integer	, 2 bytes
L	: signed integer	, 8 bytes
l	: unsigned integer	, 8 bytes
O	: bool	, 1 bit

```
int TTree_simple () {
  Int_t det;
  Float_t energy , time;

  TFile f ("simple.root", "RECREATE");
  TTree t ("tree", "My tree");
  t.Branch ("Det" , &det   , "det/I"   );
  t.Branch ("En"  , &energy, "energy/F");
  t.Branch ("Time", &time  , "time/F"  );

  TRandom3 r; r.SetSeed ();
  for (int i = 0; i < 100; i++) {
    det    = r.Integer (24);
    time   = r.Rndm() * 20.;
    energy = r.Rndm() * 30.;
    t.Fill ();
  }
  t.Write ();
  return 0;
}
```

Making an entry in the tree: `t.Fill ()`

Writing the tree in a file: `t.Write ()`

TTree cont.

Inspection of the tree in an interactive session

```
root -l simple.root
root[0] tree->Print ()
******************************************************************************
*Tree    :tree      : My tree                                                  *
*Entries :      100 : Total =            3169 bytes  File  Size =       1701 *
*        :          : Tree compression factor =   1.21                       *
******************************************************************************
*Br    0 :Det       : det/I                                                    *
*Entries :      100 : Total  Size=        936 bytes  File Size  =        230 *
*Baskets :        1 : Basket Size=      32000 bytes  Compression=   2.04     *
*.............................................................................*
*Br    1 :En        : energy/F                                                 *
*Entries :      100 : Total  Size=        943 bytes  File Size  =        469 *
*Baskets :        1 : Basket Size=      32000 bytes  Compression=   1.00     *
*.............................................................................*
*Br    2 :Time      : time/F                                                   *
*Entries :      100 : Total  Size=        941 bytes  File Size  =        471 *
*Baskets :        1 : Basket Size=      32000 bytes  Compression=   1.00     *
*.............................................................................*

root[1] tree->Show (10)
======> EVENT:10
 det             = 10
 energy          = 3.10897
 Time            = 5.81155

root[2] tree->Scan ()
************************************************
*    Row   * Det.Det.d * En.En.ene * Time.Time *
************************************************
*        0 *         1 * 2.7607548 * 2.8281364 *
*        1 *        12 * 13.696406 * 2.2420666 *
*        2 *        12 * 21.884300 * 11.228475 *
*        3 *        11 * 10.673481 * 10.060612 *
*        4 *        17 * 16.964376 * 18.435609 *
*        5 *         5 * 9.2536840 * 7.2596163 *
```

TTree cont.

Plotting the histogram of a variable (variables, combination of variables, etc)

```
root[0] tree->Draw ("energy")
root[1] tree->Draw ("sqrt(energy)")
root[2] tree->Draw ("time:energy", "", "colz")
root[3] tree->Draw ("time:Entry$" )
```

← Example of function of variable

← 2-dimensional plot

← **Entry$** is a special keyword = entry number

Plotting the histogram of a variable with some filters (cuts) required

```
root[4] tree->Draw ("time", "det>14 && det<23")
```

Projection of variables from a tree to a histogram

```
root[5] tree->Project (
Long64_t Project (const char* hname, const char* varexp,
                  const char* selection = "" , Option_t* option = "" ,
                  Long64_t nentries = 1000000000 , Long64_t firstentry = 0)

root[5] TH1F henergy ("henergy", "", 15, 0., 30. );
root[6] tree->Project ("henergy", "energy", "det<=10" );
root[7] henergy.Draw ();
```

Caution: while projecting onto 2D histograms, an order in the `varexp` string is "first Y : then X"

Cuts (TCut)

```
root[8]  TCut cut1 ("det<=10") , cut2 = "det>=20" ;
root[9]  henergy.Reset ();
root[10] tree->Project ("henergy", "energy", cut1 || cut2 );
root[11] tree->Draw ("energy", cut1 && "Entry$ <= 50" );
```

← One can combine TCut with *string*

TTree cont.

Graphical cut performed on TH2 (TCutG)

```
$ wget www.fuw.edu.pl/~kpias/ctnp/auau_1.23AGeV_8dsts.root
$ root -l auau_1.23AGeV_8dsts.root

root[1] wars_tree->Draw ("dEdxToF:totmom", "totmom<1500 && dEdxToF<15.");
```

① From the menue of the TCanvas: View → Toolbar , then  .

② By clicking mouse – mark the vertices of the polygon. Double click to finish.

③ A pointer to the TCutG object is available in the session: TCutG* CUTG .

```
root[2] wars_tree->Draw ("dEdxToF:totmom", "totmom<1500 && dEdxToF<15. && CUTG")
root[3] CUTG->Draw ("same")
```

By using the `IsInside` method we can examine if the pair of coordinates lies inside the contour, e.g.:

```
root[4] CUTG->IsInside ( 500, 7 )
```

The cut object can be renamed, as well as stored in a root file:

```
root[5] CUTG->SetName ( "mycutg" );
root[6] TFile f ( "mycutg.root" , "recreate");  mycutg->Write();
```

However, if we want to get it from a file and use as a tree selection, we first have to assign variables to axes:

```
$ nice root -l auau_1.23AGeV_8dsts.root
root[0] TFile filecut ( "mycutg.root" );
root[1] TCutG* cg1 = (TCutG*) filecut.Get ("mycutg");
root[2] cg1->SetVarX ("totmom");  cg1->SetVarY ("dEdxToF");
root[3] _file0->cd();
root[4] wars_tree->Draw ("dEdxToF:totmom","totmom<1500 && dEdxToF<15. && mycutg");
```

TTree cont.

Trick for drawing from TTree into user-defined histogram

By default, for drawing ROOT creates a temporary histogram named `htemp` with predefined structure.
A trick to override these defaults is:

```
root[5] wars_tree->Draw ("X >> histName(nBins, Xmin, Xmax)")
```

which can be nicely generalized to 2-Dim :

```
root[5] wars_tree->Draw ("Y:X >> histName(nBinsX,Xmin,Xmax,nBinsY,Ymin,Ymax)")
```

Quick TTree manipulation in ROOT macro, including functions on variables:

```
double mtm (double pt, double m) {
  return sqrt (pt*pt + m*m) - m;
}

int ttree_project_fun () {
  TFile* fin = new TFile ("auau_1.23AGeV_8dsts.root");
  TTree* tin = (TTree*) fin->Get ("wars_tree");
  TCut cSelectProtons ("mass>650 && mass<1200");

  tin->Draw ( " mtm (pt,mass) " , cSelectProtons );

  return 0;
}
```

- if you need to draw a more complicated expression based on variables, you can create a function as above – and use it in the Draw formula string.

Getting the TTree from the ROOT file + readout of data from TTree:

① Connect to the tree:

```
TTree* t = (TTree*) f.Get ("tree");
```

② Connect the variables to the branches:

```
t->SetBranchAddress ("name",&variable);
```

③ Get the number of entries:

```
t->GetEntries();
```

④ Read the full event into the variables:

```
t->GetEntry (i);
```

```
int TTree_simple_read () {
  Int_t det;
  Float_t energy , time;

  TFile f ("simple.root");
  TTree* t = (TTree*) f.Get ("tree");

  t->SetBranchAddress ("Det" , &det   );
  t->SetBranchAddress ("En"  , &energy);
  t->SetBranchAddress ("Time", &time  );

  for (int i=0; i<t->GetEntries(); i++)
  {
    t->GetEntry (i);
    cout << setw( 5) << det
         << setw(12) << time
         << setw(12) << energy << endl;
  }
  return 0;
}
```

Status of branches

One can define, which branches should be analysed, and which ones – not. Before the event loop, one should issue:

```
TTree::SetBranchStatus ("branch", status);
```

status: (0) / 1 = (in)active

"branch" = "*" : (de)activation concerns all the branches

Notice: Deactivation of unnecessary branches **shortens** the analysis time (important for large data files!)

Creating new TTree from the old one

① **Impose a cut** on an original tree → create a resultant tree.

```
TTree* NewTree = tree_original->CopyTree (" {some cut} ");
```

```
int TTree_cut_and_branch () {
 TFile fin ("simple.root");
 TTree* tree_in = (TTree*) fin.Get ("tree");

 TFile fout_cut ("simple_cut.root", "RECREATE");
 TTree* tree_cut = tree_in->CopyTree ("det < 10") ;
 tree_cut->Write();
 fout_cut.Close();

 tree_in->SetBranchStatus ("*", 0);
 tree_in->SetBranchStatus ("Time", 1);
 TFile fout_bran ("simple_bran.root", "RECREATE");
 TTree* tree_bran = tree_in->CloneTree();
 tree_bran->Write();
 fout_bran.Close();
}
```

② **Select some branches** from an original tree and create a resultant tree.

```
tree_original->SetBranchStatus ("*", 0);
tree_original->SetBranchStatus ("{selected branch}", 1);
TTree* NewTree = tree_original->CloneTree();
```

Caution: here, the new tree is connected to the old one.
The solution above works e.g. if we just need to store the new tree in a file.

Adding a Friend tree to your tree

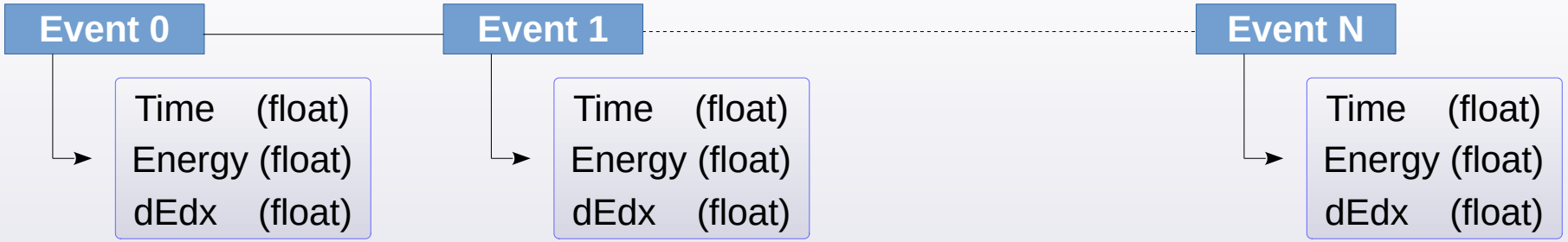
If you have T1 and T2 trees with the same No. of entries, you can analyse them together “as one tree”.
The tool for that is `T1.AddFriend (T2)` .
You will not merge trees in a file (or memory), but effectively you can `Draw`, `Scan`, `Project` them together.

```
int TTree_AddFriend() {
  TFile* fin = new TFile ("simple_branch.root");
  TTree* t1 = fin->Get<TTree> ("tree_time"  ),
       * t2 = fin->Get<TTree> ("tree_energy");
  t1->AddFriend (t2) ;

  t1->Draw ("time:energy");
  return 0;
}
```

TNtuple (TNtupleD) Simple trees composed of only *floats* (*doubles*)

Even simpler data scheme (case of floats) :



- Variables are defined in the constructor.
- For every variable a branch is made.
- Filling is done by giving variable values
- Direct filling up to 15 variables:

```
Fill (var1, var2, …)
```

- … or via array:

```
Fill (Float_t* x)
```

```
int TNtuple_example () {
  Float_t energy , time, dEdx;

  TFile f ("tntuple.root", "RECREATE");
  TNtuple n ("tntuple", "My ntuple", "Time:En:dEdx" );

  TRandom3 r; r.SetSeed ();
  for (int i=0; i<100; i++) {
    time   = r.Rndm() * 20.;
    energy = r.Rndm() * 30.;
    dEdx   = r.Rndm() * 0.5;
    n.Fill (time, energy, dEdx);
  }
  n.Write();
  return 0;
}
```

Merging data from ROOT files with the same structure

If we need to analyse a series of files with TTree that has the same structure, we can of course make a loop: open i-th file, connect the tree and branches, analyse data, and close that file. However, if we store the resulting histograms in a common output file, one often has to switch back and forth the `gDirectory`.

There is an alternative: merging the input data.

TChain. Object being effectively a batch of consecutive TTree objects in specified files. Let's assume that every input file has a TTree called "T".

① Create the TChain:

```
TChain myChain ("T");
```

② Add subsequent files:

```
myChain.Add ("file1.root");
myChain.Add ("file2.root");
myChain.Add ("file3.root");
```

③ Since now we use the `myChain` object, as if it was the common input tree.

The **hadd** executable, runnable from prompt :

```
> hadd  data_merged.root  data_1.root data_2.root ....
                          ( or: data_*.root )
```

Caution: the maximum size of resulting file is set to **100 GB**.
For bigger data there is a **TFileMerger** class. One can use this macro.

TTree cont. Handling the TVector*N* {N = 2, 3} / TLorentzVector object in an event:

Storage:

```
int TTree_TVector () {

 TVector3 v3;
 TVector3* pv3 = &v3;

 TLorentzVector vL;
 TLorentzVector* pvL = &vL;

 TFile file ("TTree_TVector.root", "recreate");

 TTree* ttree = new TTree ("ttree", "ttree");
 ttree->Branch ("v3", "TVector3"       , &pv3);
 ttree->Branch ("vL", "TLorentzVector", &pvL);

 TRandom3 r; r.SetSeed (0);

 for (int evt = 0; evt < 100; evt++)
 {
   v3.SetXYZ  (r.Rndm(), r.Rndm(), r.Rndm());
   vL.SetXYZT (r.Rndm(), r.Rndm(),
               r.Rndm(), r.Rndm() );
   ttree->Fill();
 }
 ttree->Write();

 file.Close();
 return 0;
}
```

Readout:

```
int TTree_TVector_read () {

 TVector3 v3;
 TVector3* pv3 = &v3;

 TLorentzVector vL;
 TLorentzVector* pvL = &vL;

 TFile f ("TTree_TVector.root");

 TTree* ttree = (TTree*) f.Get ("ttree");
 ttree->SetBranchAddress ("v3", &pv3 );
 ttree->SetBranchAddress ("vL", &pvL );

 for (int evt=0; evt < ttree->GetEntries(); evt++)
 {
   ttree->GetEvent (evt);

   cout << "[" << evt << "]: ["
        << fixed << setprecision (3) <<
        << v3[0] <<" : "<< v3[1] << " : "
        << v3[2] << "]" << "\t";

   cout << "["   << vL[0] << " : " << vL[1]
        << " : " << vL[2] << " : " << vL[3]
        << "]\n";
 }
 f.Close();

 return 0;
}
```

Notice: Methods of `TVector3` and `TLorentzVector` classes work. E.g.: `tree->Draw ("v3.Mag()")`

TTree cont. Events with variable number of particles (the simplest way)

Storage:

```
int TTree_EventManyParticles () {
 Int_t Npart;
 Int_t det[500];
 Float_t energy[500] , time[500];

 TFile f ("manyparticles.root", "RECREATE");
 TTree t ("tree", "My tree");
 t.Branch ("Npart", &Npart, "Npart/I");
 t.Branch ("Det"  , det   , "det[Npart]/I");
 t.Branch ("Time" , time  , "time[Npart]/F");
 t.Branch ("En"   , energy, "energy[Npart]/F");

 TRandom3 r; r.SetSeed ();
 for (int ievt=0; ievt < 100 ; ievt++)
 {
  Npart = r.Integer(6);
  cout << "Event " << ievt
       << " has " << Npart << " particles.\n";
  for (int ipart=0; ipart<Npart; ipart++)
  {
    det   [ipart] = r.Integer (24);
    time  [ipart] = r.Rndm() * 20.;
    energy[ipart] = r.Rndm() * 30.;
    cout << setw(10) << det   [ipart]
         << setw(12) << time  [ipart]
         << setw(12) << energy[ipart] << endl;
  }
  t.Fill ();
 }
 t.Write();
 return 0;
}
```

Readout:

```
int TTree_EventManyParticles_read () {
 Int_t Npart;
 Int_t det[500];
 Float_t energy[500] , time[500];

 TFile f ("manyparticles.root", "READ");
 TTree* t = (TTree*) f.Get ("tree");
 t->SetBranchAddress ("Npart", &Npart );
 t->SetBranchAddress ("Det"  , det   );
 t->SetBranchAddress ("Time" , time  );
 t->SetBranchAddress ("En"   , energy );

 cout << "* This tree has "
      << t->GetEntries() << " entries.\n\n";

 for (int ievt=0; ievt<t->GetEntries(); ievt++)
 {
  t->GetEntry (ievt);
  cout << "* Event " << ievt
       << " has " << Npart << " particles:\n";

  for (int ipart=0; ipart<Npart; ipart++)
  {
   cout << setw(10) << det   [ipart]
        << setw(12) << time  [ipart]
        << setw(12) << energy[ipart] << endl;
  }
 }
 return 0;
}
```

Drawback: it's necessary to predefine the dimension limit (here: 500). Dynamic memory allocation does not work.

TTree cont. Trees with user-defined objects

Event → Branch: Object { Det (int) , Time (float) , Energy (float) }

The implementation recipes changed throughout ROOT versions.
Method suggested for ROOT 5,6 : via **ACLiC** mechanism. Below – demonstrator code for a minimal object.

1. Create a header file `myClass.h`

```
#ifndef __myClass__
#define __myClass__
#include "TObject.h"

class myClass : public TObject {
 public:
  Int_t det;        // det
  Double_t ToF;     // ToF
  Double_t Energy; // Energy

  myClass() { det = 0;
              ToF = 0.; Energy = 0.; }

 //  Declarations of our other methods

  ClassDef (myClass,1)  // My simple class
};
#endif
```

without semicolon

2. Create the class source code `myClass.cxx` :

```
#include <iostream.h>
#include <myClass.h>

ClassImp(myClass)

// Implementations of our other methods
```

without semicolon

→ Class must inherit after `TObject`.
→ It must contain the `()` constructor.
→ `ClassDef` and `ClassImp` are the preprocessor macros, which paste here the additional builtin methods, e.g. enabling the storage of object in a TTree (`::Streamer`) or creating the documentation.

TTree cont. Trees with user-defined objects

3. Encoding the TTree, which for every event stores 1 object of `myClass` class.

```
#ifdef __CINT__
#else
#include "myClass.h"
#endif

int TTree_myObject ()
{
  if (!TClass::GetDict("myClass"))
    gROOT->ProcessLine (".L myClass.cxx+");

  TRandom3 r; r.SetSeed ();
  myClass* myObj = new myClass ();

  TFile f ("myobjs.root", "recreate");
  TTree* t = new TTree ("tree", "My Tree");
  t->Branch ("myObj", &myObj, 8000, 0);

  for (int evt = 0; evt < 100; evt++) {
    myObj->det    = r.Integer (24) ;
    myObj->ToF    = r.Rndm() * 20. ;
    myObj->Energy = r.Rndm() * 30. ;
    t->Fill();
  }
  t->Write();
  t->Print();
  f.Close();
  return 0;
}
```

Enables both ROOT 5/6 versions

4. Encoding the readout of such a TTree.

```
#include "myClass.h"

int TTree_myObject_read ()
{
 myClass* myObj = new myClass ;

 TFile f ("myobjs.root");
 TTree* t = (TTree*) f.Get ("tree");
 t->SetBranchAddress ("myObj", &myObj);

 cout << "This tree has "
      << t->GetEntries() << " events.\n";
 for (int evt=0; evt < t->GetEntries(); evt++)
 {
  t->GetEntry (evt);

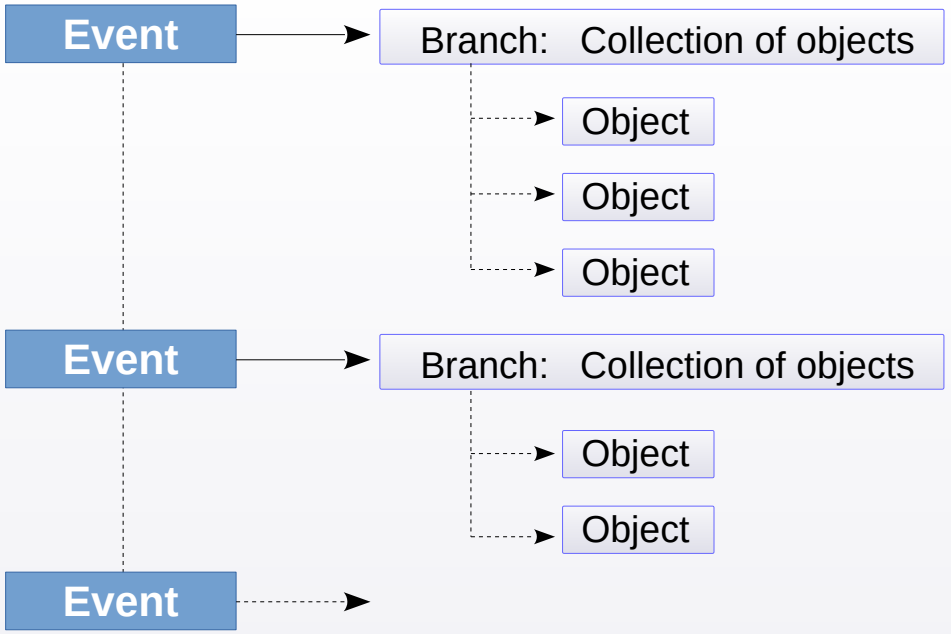
  cout << "[Event " << evt << "] :  ["
       << setw( 4) << myObj->det
       << setw(12) << myObj->ToF
       << setw(12) << myObj->Energy
       << " ]\n";
 }
 f.Close();

 return 0;
}
```

The `.L` command will create 2 files on the current path:

- `myClass_cxx.so` (compiled object – *shared library*)
- `myClass_cxx.d` ("dependencies"; information for ROOT)

TTree cont. Collection (array) of objects (of the same class) stored in a TTree event



- In order to encode such a structure, we'll use the object of `TClonesArray` class.

  It is an array of objects of the same class. These objects must inherit after `TObject` .
  A created `TClonesArray` is given the default initial size: 1000 objects.
  Once we insert an element at higher position, the enlargement of dimension is done automatically.

- Nb. ROOT features several kinds of arrays for objects (so-called `Collections`).
  E.g., within `TOrdCollection` one can store objects of different classes (inheriting after `TObject`) .

- On the next slides: exemplary codes that save and read such a "structure" .

TTree cont.

Collection of objects of the same class

- Exemplary code to store the TCloneArrays in the TTree entries:

– Create the `TClonesArray` object, giving the name of class of elements. Creating also the pointer to TClassArray.

If we don't set the size, the default size will be 1000 elements.
If we overfull, the array will resize.

– In branch's definition we give the pointer to the pointer of TClassArray.

– Cleaning the array

– Creating a new object of `myClass` class will automatically store it in the array at a given position.

```
#ifdef __CINT__
#else
#include "myClass.h"
#endif

int TTree_TClonesArray ()
{
 if (!TClass::GetDict("myClass"))
   gROOT->ProcessLine (".L myClass.cxx+");

 TFile f ("clonesarray.root", "recreate");

 TClonesArray* myArrayPtr = new TClonesArray ("myClass");
 myClass* myObjectPtr;

 TTree* t = new TTree ("tree", "My Tree");
 t->Branch ("ObjClones", &myArrayPtr , 256000, 0);

 TRandom3 r;  r.SetSeed();

 for (int evt=0; evt<100; evt++) {
   myArrayPtr->Clear();
   int Npart = rand() % 6;

   cout << "Event " << evt << " has "
        << Npart << " particles. \n";
   for (int iPart = 0; iPart < Npart; iPart++)
   {
     myObjectPtr = (myClass*)
                   myArrayPtr->ConstructedAt (iPart);
     myObjectPtr->det    = r.Integer (24);
     myObjectPtr->ToF    = r.Rndm();
     myObjectPtr->Energy = r.Rndm();
   }
   t->Fill();
 }
 t->Print();  t->Write();
 f.Close();
 return 0;
}
```

TTree cont. Collection of objects (of the same class) stored in a TTree event

Exemplary code to read out the arrays of objects from TTree entries:

- Create 1x `TClonesArray` through pointer.
- We connect to a branch, giving the pointer to the pointer to the TClonesArray object.
- Clearing array before event readout
- If we get the event, the `TClonesArray` object is filled automatically.
- Iteration over array elements.

```
#include "myClass.h"

int TTree_TClonesArray_read ()
{
 TFile f ("clonesarray.root");

 TClonesArray* myArrayPtr = new TClonesArray ("myClass");

 TTree* t = (TTree*) f.Get ("tree");
 t->SetBranchAddress ("ObjClones", &myArrayPtr );

 myClass* myObjPtr;

 for (int evt = 0 ; evt < t->GetEntries() ; evt++)
 {
  myArrayPtr->Clear();
  t->GetEvent (evt);
  int Npart = myArrayPtr->GetEntries() ;

  cout << "\nEvent " << evt << " has "
       << Npart << " particles: \n";

  for (int iPart = 0; iPart < Npart; iPart++)
  {
   myObjPtr = (myClass*) myArrayPtr->At (iPart);

    cout << " ["  << setw (2) << myObjPtr->det
         << ":  " << setw (9) << myObjPtr->ToF
         << " , " << setw (9) << myObjPtr->Energy << " ] \n";
  }
 }

 f.Close();
 return 0;
}
```

Finding the root of function

- ROOT contains numerical algorythms, borrowed from the GSL library.
  In script we'll consider 2 of them.

- We start the root search by deciding if it's enough that method uses only the function (e.g. bisection), or a derivative is needed (e.g.. Newton).

① We write function (+ derivative if needed)

② We put function (+derivative if needed) into a special object called "wrapper".

③ We create the `RootFinder` tool, and set the type of algorythm.
Here we use: bisection and Newton.
Full set of methods is available here.

④ We link the tool and the functions

⑤ We evaluate the root finder.

⑥ A result is given by `Root()` method.

```
#include <Math/RootFinderAlgorithms.h>
#include <Math/RootFinder.h>
#include <Math/Functor.h>

using namespace ROOT::Math;

double myfunc (double x) {
  return 3*x - 10;
}

double myfunc_deriv (double x) {
  return 3 ;
}

void macro_RootFinder ()
{
  Functor1D f ( &myfunc );
  RootFinder k ( RootFinder::kGSL_BISECTION ) ;
  k.SetFunction (f, 1, 10);
  k.Solve ();
  cout << "Root via bisection: " << k.Root()
       << endl;

  GradFunctor1D g ( &myfunc , &myfunc_deriv );
  k.SetMethod ( RootFinder::kGSL_NEWTON );
  k.SetFunction ( g , 4. );
  k.Solve ();
  cout << "Root via Newton   : " << k.Root ()
       << endl;
}
```

Interpolation between points

- Available tool:
  ROOT::Math::Interpolator,
  borrowed from the GSL library.

- Algorithm steps:

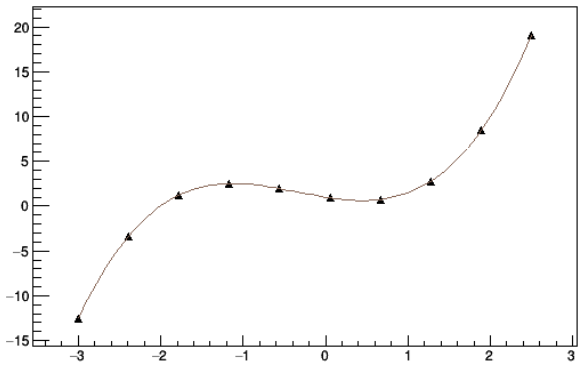
① Store your data points in `double*` or `vector<double>` arrays

② Create the `Interpolator` object, giving the interpolation type:

- kLINEAR
- kPOLYNOMIAL
- kCSPLINE
- kCSPLINE_PERIODIC
- kAKIMA
- kAKIMA_PERIODIC

③ Pass your data using `SetData` method

④ Values of interpolation function are available immediately via `Eval` method




```
void macro_interpolation ()
{
  float xmin = -3, xmax = 2.5;
  Int_t Ndata = 10;
  double xi[Ndata], yi[Ndata];

  TF1* funPoly = new TF1 ("fp",
       "[0]+[1]*x+[2]*x^2+[3]*x^3", xmin, xmax);
  funPoly->SetParameters (1, -1.5, 1, 1);

  for (int i = 0; i < Ndata; i++) {
   xi[i]= i * (xmax - xmin) / (Npts-1) + xmin;
   yi[i]= funPoly->Eval ( xi[i] );
  }

  ROOT::Math::Interpolator inter ( Ndata ,
        ROOT::Math::Interpolation::kPOLYNOMIAL );

  inter.SetData (Npts, xi, yi);

  int Nprobes = 100;
  double Xint[Nprobes], Yint[Nprobes];

  for (int i = 0; i < Nprobes; ++i ) {
    Xint[i] = i*(xmax-xmin)/(Nprob-1) +xmin;
    Yint[i] = inter.Eval ( Xprob[i] );
  }

  TGraph* gf = new TGraph (Npts, xi, yi);
  gf->Draw ("AP");

  TGraph* gi = new TGraph (Nprob, Xprob, Yinter);
  gi->Draw ("SAME L");
}
```

Compilation of standalone C++ code with ROOT functionality

Necessary steps

1. It should be a “decent”, compilable code.
   E.g. should contain the `main` function.

2. In the code we have to include all the headers corresponding to used ROOT objects, e.g.:

   ```
   #include "TH1F.h"
   ```

3. If we use graphics, we should add the **TRint** graphical interface. In order to do that,

   - include the `TRint.h` header
   - Declare the `main` function with the input arguments:

     ```
     int main  (int argc, char* argv[] )
     ```

   - In the `main` function we create the `TRint` object

     ```
     TRint myRint ("myRint", &argc, argv);
     ```

4. Compilation with “typical” tools – via :

   ```
   g++ code.C `root-config --cflags --libs`
   ```

   In case of extra libraries, we add them at the end:
   `-lMathMore` for `Root::Math`
   `-lSpectrum` for `TSpectrum`, `-lTMVA` for `TMVA`

Exemplary code in C++ : fit of TF1 to TGraph
We compile it as above.

Cstandalone_fitTGraphErrors.C

```
#include "TF1.h"
#include "TGraphErrors.h"
#include "TMath.h"

#include "TRint.h"       // graphics interface
#include "TCanvas.h"

using namespace std;

Double_t myFun (Double_t* xarg, Double_t* par)
{
  Double_t x = xarg[0] , result = 0.;

  for (int st=0; st<=3; st++)
    result += par[st] * TMath::Power (x, st);

  return result;
}


int main  (int argc, char* argv[])
{
 TRint myRint ("myRint", &argc, argv);
 TCanvas* can1 = new TCanvas ("can1",
                              "can1", 600, 400);

 TGraphErrors gr ("dataPoints.txt");
 gr.SetTitle ();

 TF1 fun ("fun", myFun , -3, 5, 4);
 fun.SetParameters (-1. , 1. , -6. , 1.);
 gr.Fit ( &fun , "" );
 gr.Draw ("AP");

 can1->Update();
 cin.ignore();
 return 0;
}
```

Compilation through *make*

Within Linux, many applications are installed from sources using `make`.
The aim of `make` is the compilation and, if needed, linking of the package.

You can see the minimal `make` macro for the code from previous page. It doesn't perform linking, but has options for linking to ROOT libraries ready.

makefile

```
CC=g++
CFLAGS=`root-config --cflags --libs`
LDFLAGS=`root-config --glibs`

SOURCE=Cstandalone_fitTGraphErrors.C
TARGET=Cviamake_fitTGraphErrors

Cviamake_fitTGraphErrors: $(SOURCE)
        $(CC) -o $(TARGET) $(SOURCE) $(CFLAGS)

clean:
        rm -f ./*~ ./*.o ./Cviamake_fitTGraphErrors
```

Unification of code

Solutions are available for a common code, which handles two variants of launching:

① as a compilable code
(eg. via g++ with ROOT flags)

② as a macro in interactive session.

One of solutions is the usage of `#if defined` preprocessor commands.

The demonstrator code shows also,
– how to handle the input arguments
– where to place #include headers.

```
#if defined __CINT__ || defined __CLING__

int macro_cprogram_unifier (int InputValue = 123)  {
  cout << "\n Hello, I am being interpretted." << endl;

#else

#include "TMath.h"
#include <iostream>
#include <iomanip>
using namespace std;

int main (int argc, char* argv[])  {
  cout << "\n Hello, I was compiled." << endl;
  int InputValue = (argc > 1) ? atoi (argv[1]) : 123;

#endif

  cout << "\n Okay, and this is the common portion of code.";
  cout << "\n TMath::Pi() = " << setprecision (18) << TMath::Pi();
  cout << "\n Input value (default: 123) = " << InputValue;
  cout << "\n\n";
  return 0;
}
```