Summer Students Course 2015

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CERN PH-SFT

This Course

This is an introductory ROOT Workshop, not a lecture about ROOT

Objectives:

- Become familiar with the ROOT toolkit
- Be able to use the C++ prompt
- Plot data
- Fit data
- Perform basic I/O operations

Format:

- Slides treating the most important concepts
- Hands on exercises proposed during the exposition

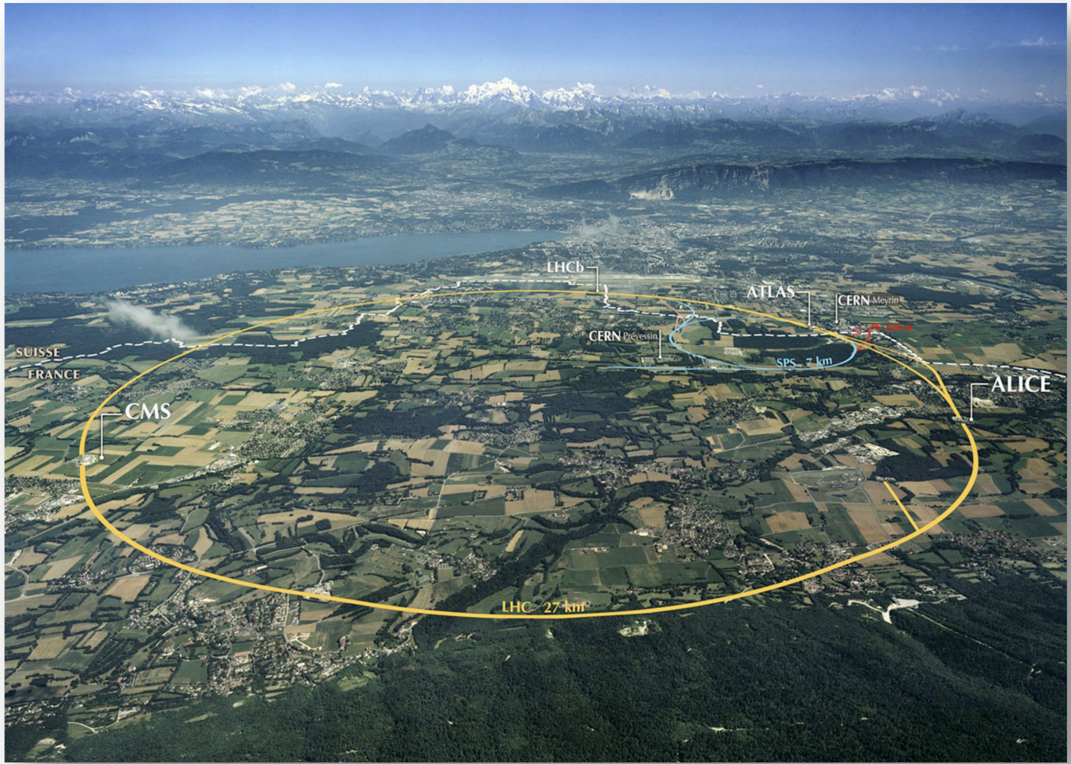
This Tutorial

These slides are supported by the **“ROOT Primer”**

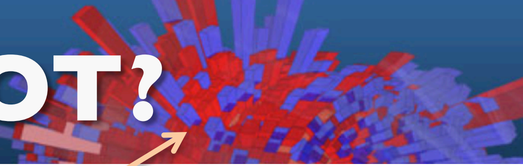
- Introductory booklet (~60 pages)
- Available on the ROOT website (html, epub, pdf): http://cern.ch/go/SV87
- Code examples will be visualised with the Jupiter Notebooks attached to the indico agenda
  - Signaled with name and the sign:

Two release series of ROOT are available: ROOT5 and ROOT6
This lecture refers to ROOT6, version 6.04

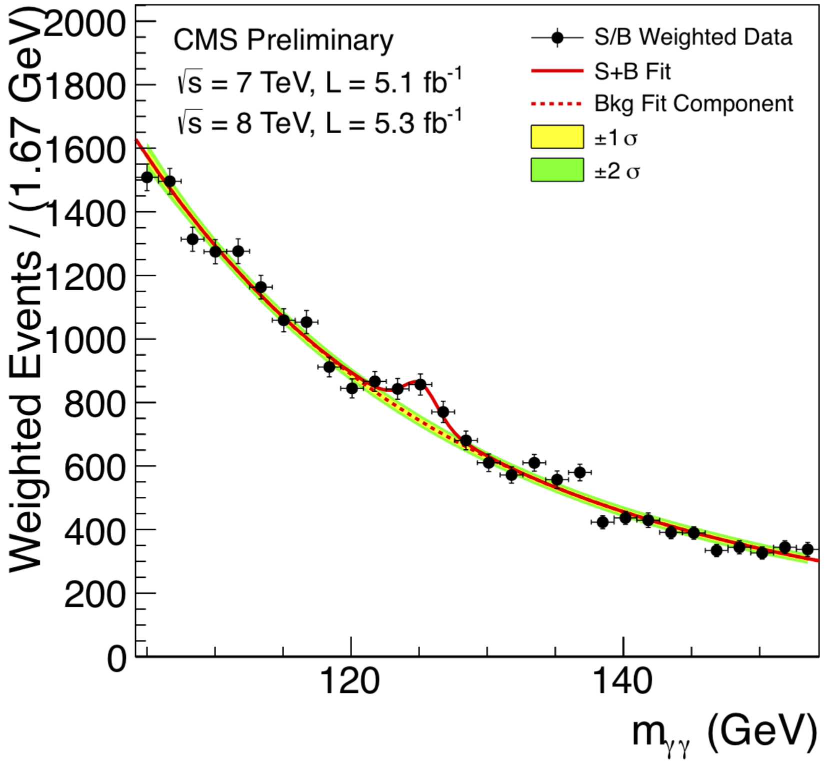
A “Quick Tour” Of ROOT

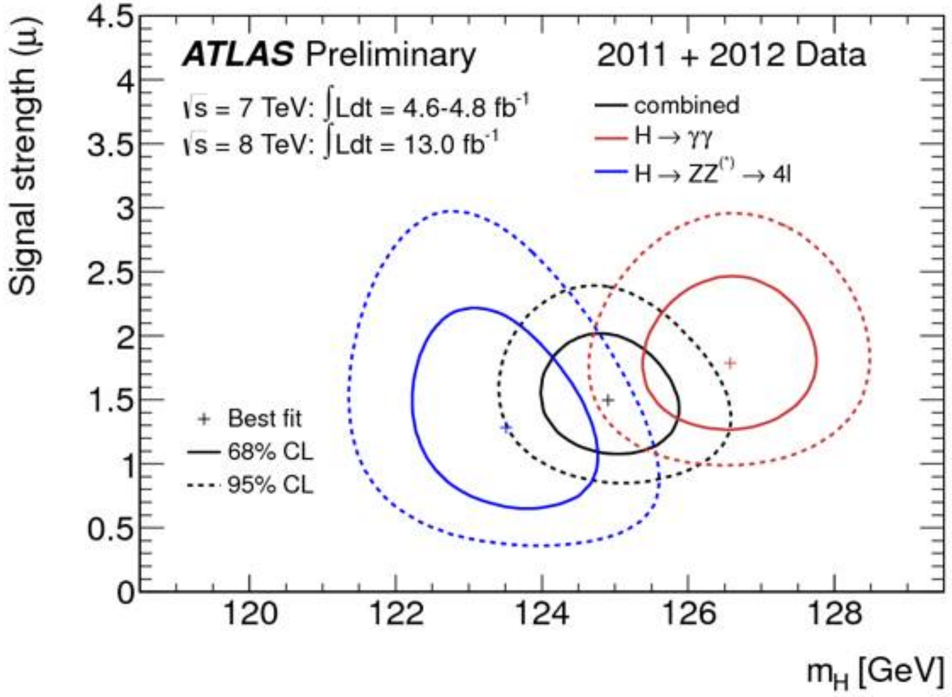


What can you do with ROOT?



LHC collision in CMS:
event display, also done with ROOT!





ROOT in a Nutshell

ROOT is a software toolkit which provides building blocks for

- Data processing
- Data analysis
- Data visualisation
- Data storage

An Open Source Project

All contributions are warmly welcome!

ROOT is written mainly in C++ (C++11 standard)

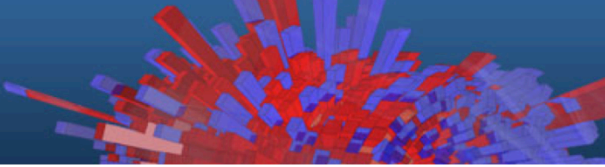
- Bindings for Python and other languages* provided

Adopted in High Energy Physics and other sciences (but also industry)

- ~250 PetaBytes of data in ROOT format on the LHC Computing Grid
- Fits and parameters' estimations for discoveries (e.g. the Higgs)
- Thousands of ROOT plots in scientific publications

* Atm only Python for the 6 series

ROOT in a Nutshell

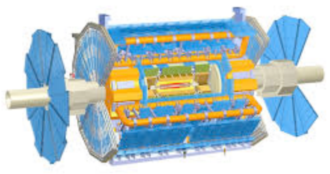


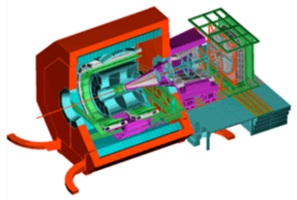
ROOT can be imagined as a family of building blocks for a variety of activities, for example:

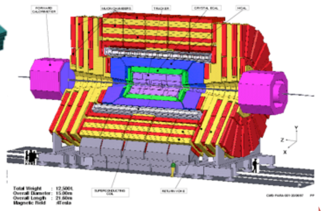
- Data analysis: histograms, graphs, trees
- I/O: row-wise, column-wise storage of **any** C++ object
- Statistical tools (RooFit/RooStats): rich modeling and statistical inference
- Math: non trivial functions (e.g. Erf, Bessel), optimised math functions (VDT)
- C++ interpretation: fully C++11 compliant
- Multivariate Analysis (TMVA): e.g. Boosted decision trees, neural networks
- And more: HTTP servering, JavaScript visualisation, advanced graphics (2D, 3D, event display).
- PROOF: parallel analysis facility

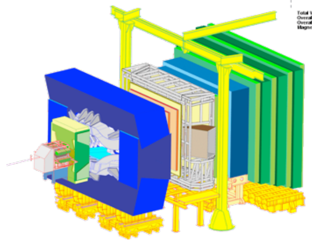
ROOT Application Domains

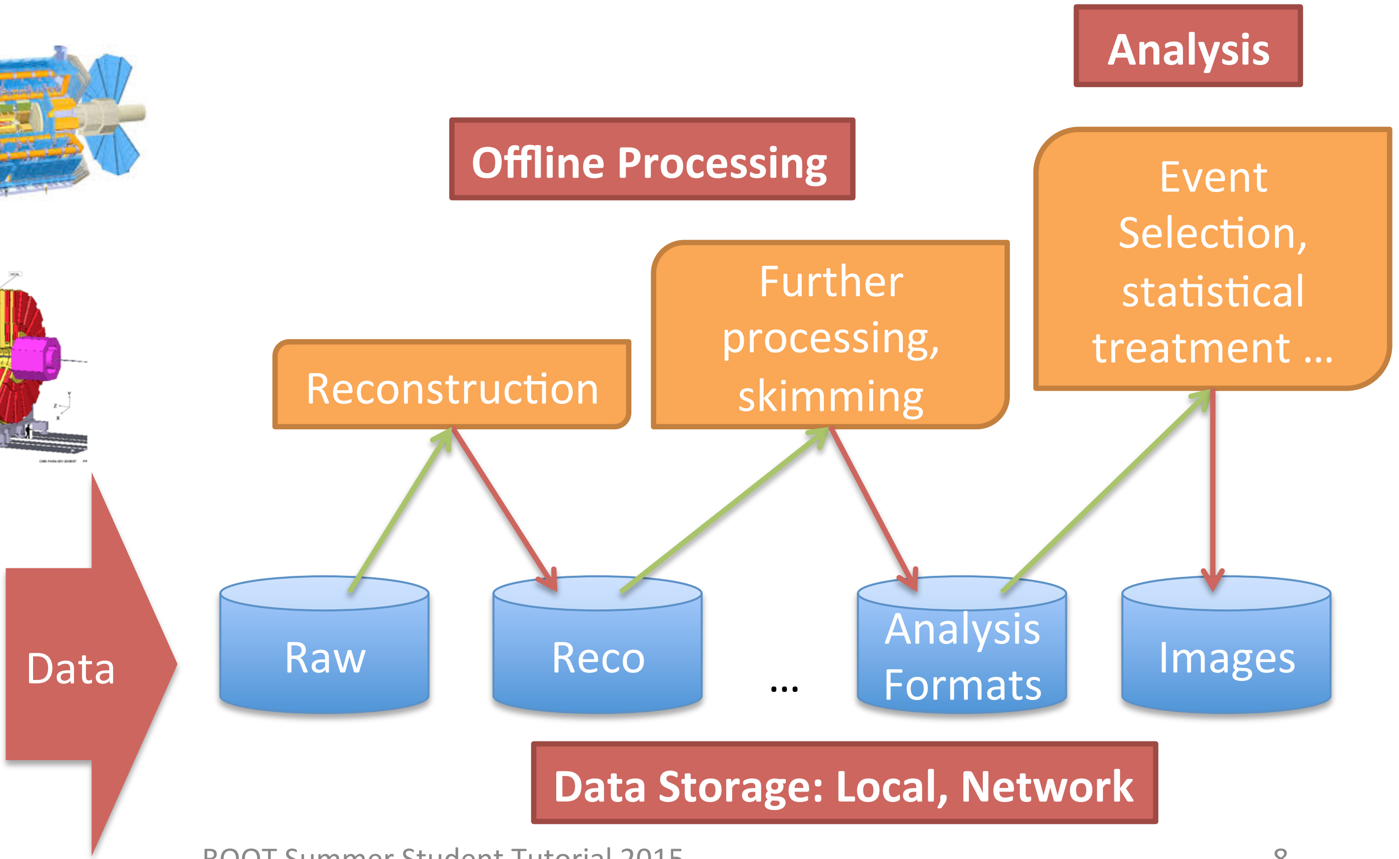
A selection of the experiments adopting ROOT









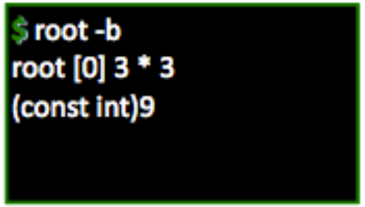

Analysis
Offline Processing
Event Selection, statistical treatment …
Further processing, skimming
Reconstruction
Data
Raw
Reco
…
Analysis Formats
Images
Data Storage: Local, Network

Event Filtering

Interpreter

ROOT is shipped with an interpreter, CLING

- C++ interpretation: highly non trivial and not foreseen by the language!
- One of its kind: Just In Time (JIT) compilation
- A C++ interactive shell.



```
$ root -b
root [0] 3 * 3
(const int)9
```

Can interpret "macros" (non compiled programs)

- Rapid prototyping possible

ROOT provides also Python bindings:

- Can use Python interpreter directly after a simple *import ROOT*
- Possible to "mix" the two languages (see more in the following slides!)

Persistency (I/O)

ROOT offers the possibility to write C++ objects into files

- Exceptional: impossible with C++ alone!
- Used for petabytes/year rates of LHC detectors.

Achieved with serialization of the objects using the reflection capabilities, ultimately provided by the interpreter

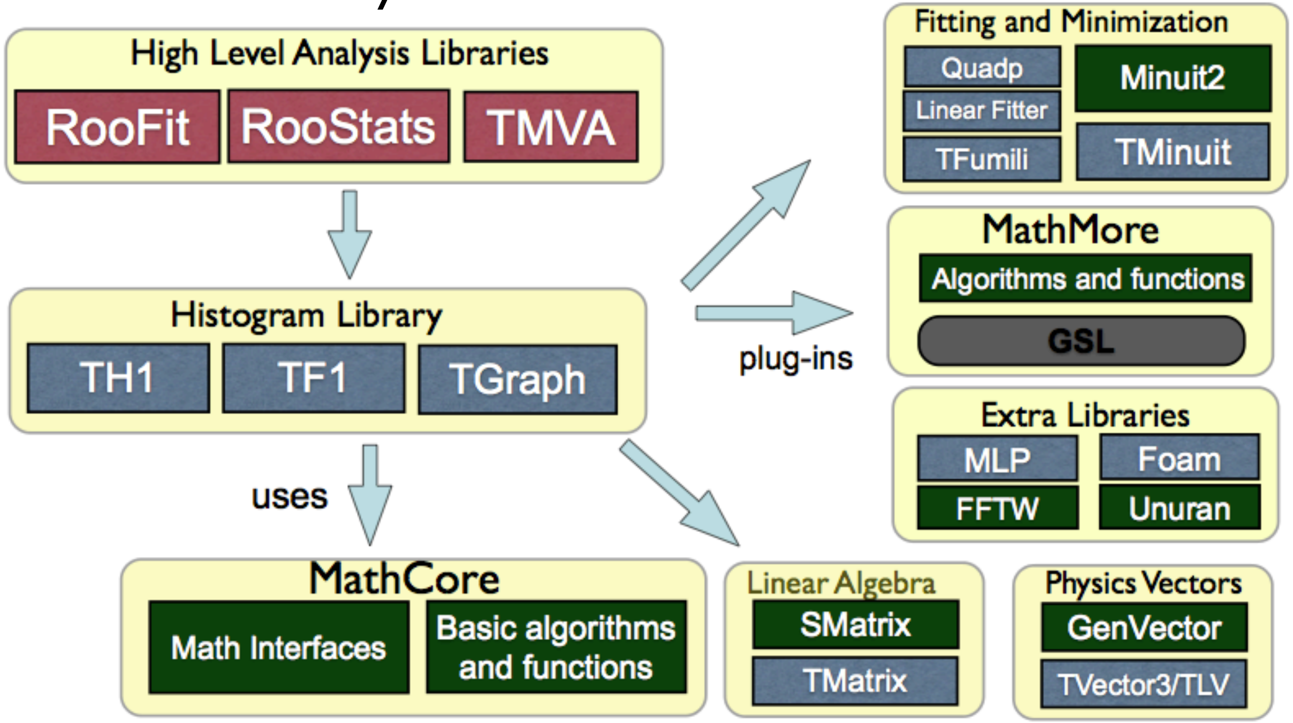
- Raw and column-wise streaming

As simple as this for ROOT objects: one method - *TObject::Write*

Cornerstone for storage of experimental data

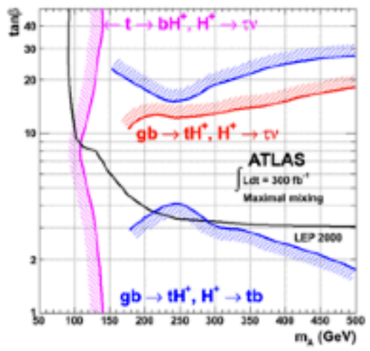
ROOT Math/Stats Libraries

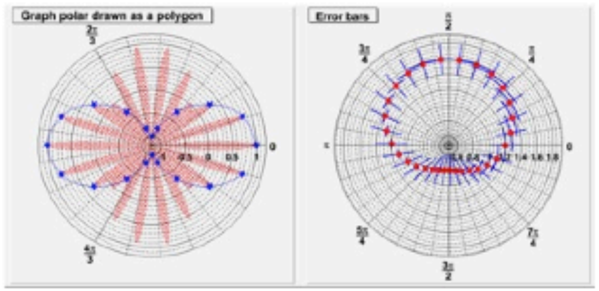
ROOT provides a reach set of mathematical libraries and tools needed for sophisticated statistical data analysis

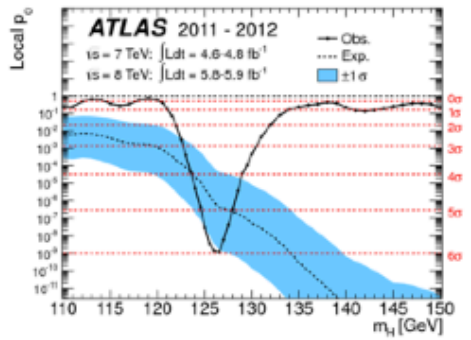


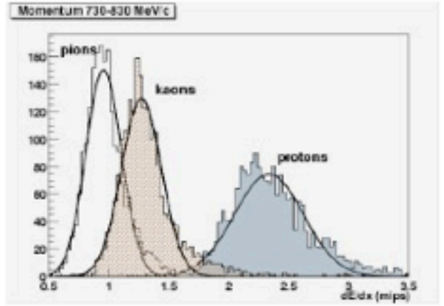
Graphics In ROOT

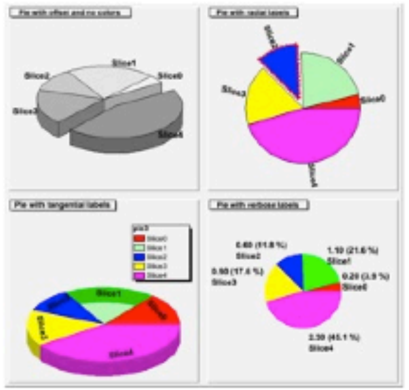
Many formats for data analysis, and not only, plots

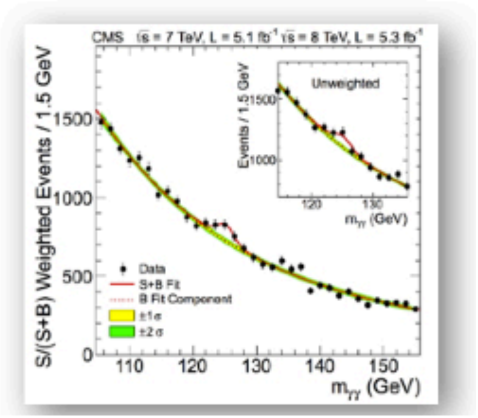










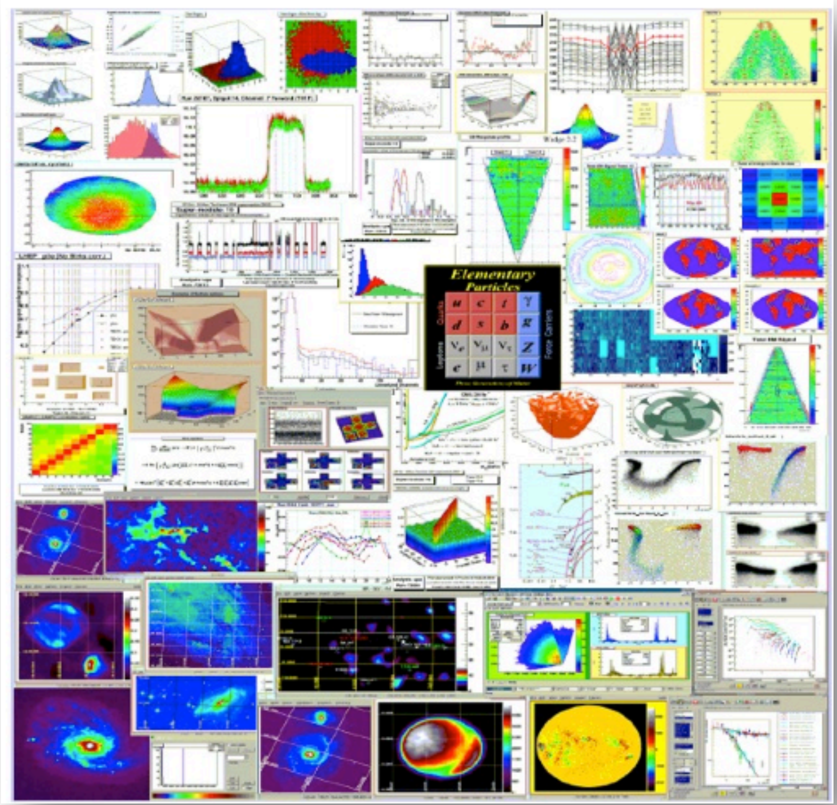


2D Graphics

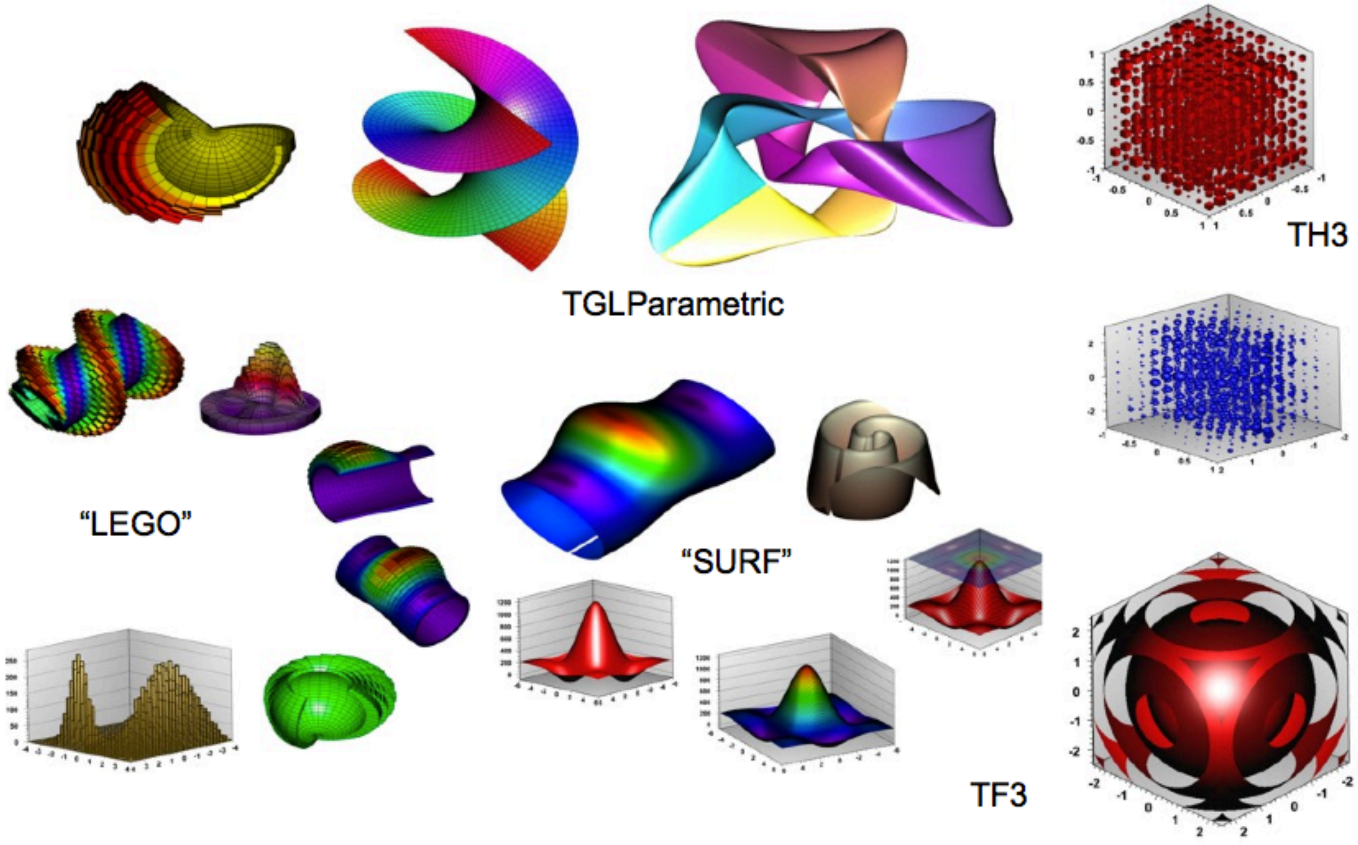
New functionalities added at every new release

Always requests for new style of plots

Can save graphics in many formats: *ps, pdf, svg, jpeg, LaTex, png, c, root*



3D Graphics



Other ROOT Features

Geometry Toolkit

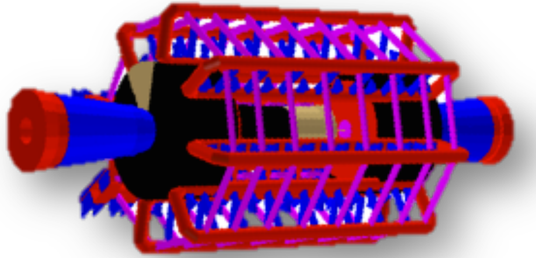
- Represent geometries as complex as LHC detectors

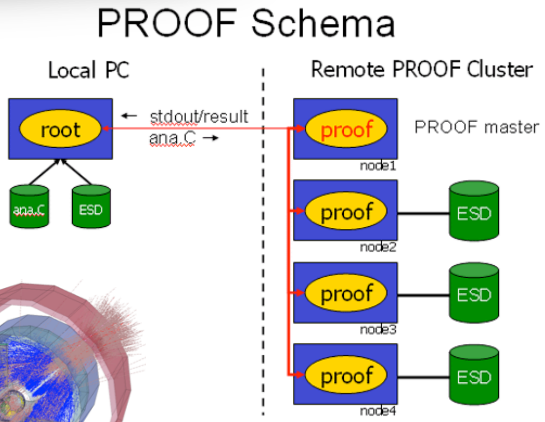
Event Display (EVE)

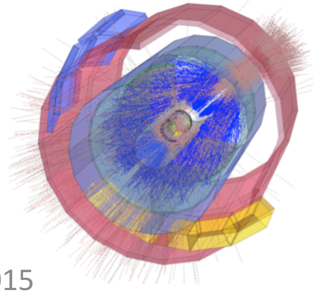
- Visualise particles collisions within detectors

PROOF: Parallel ROOT Facility

- Multi-process approach to parallelism
- A system to run ROOT queries in parallel on a large number of distributed computers
- Proof-lite: does not need a farm, uses all the cores on a desktop machine





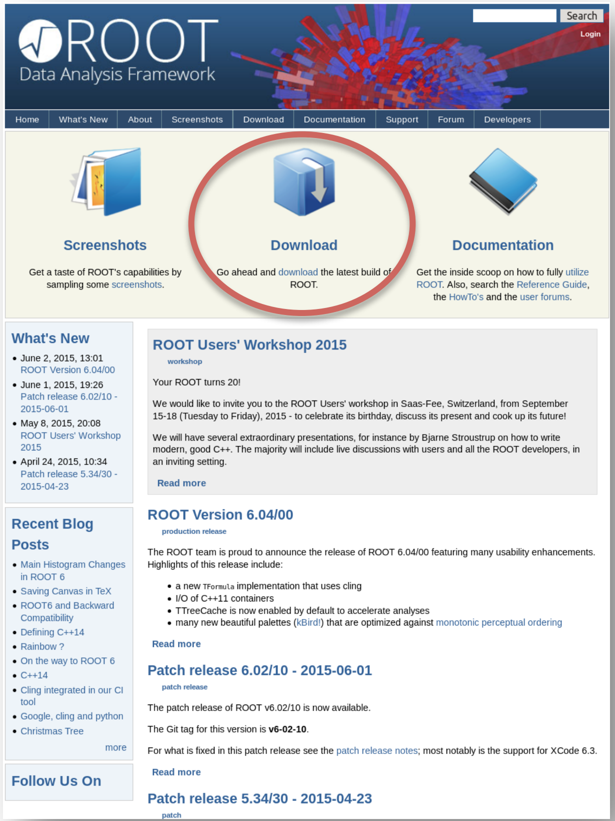


www.root.cern.ch

ROOT web site: **the** source of information and help for ROOT users

- For beginners and experts
- Downloads, installation instructions
- Documentation of all ROOT classes
- Manuals, tutorials, presentations and more
- Forum
- …

We propose to do a quick tour of the web site
Don't hesitate to use it, even today!



Screenshots

Get a taste of ROOT's capabilities by sampling some screenshots.

Download

Go ahead and download the latest build of ROOT.

Documentation

Get the inside scoop on how to fully utilize ROOT. Also, search the Reference Guide, the HowTo's and the user forums.

What's New

- June 2, 2015, 13:01 ROOT Version 6.04/00
- June 1, 2015, 19:26 Patch release 6.02/10 - 2015-06-01
- May 8, 2015, 20:08 ROOT Users' Workshop 2015
- April 24, 2015, 10:34 Patch release 5.34/30 - 2015-04-23

Recent Blog Posts

- Main Histogram Changes in ROOT 6
- Saving Canvas in TeX
- ROOT6 and Backward Compatibility
- Defining C++14
- Rainbow ?
- On the way to ROOT 6
- C++14
- Cling integrated in our CI tool
- Google, cling and python
- Christmas Tree

more

Follow Us On

ROOT Users' Workshop 2015

workshop

Your ROOT turns 20!

We would like to invite you to the ROOT Users' workshop in Saas-Fee, Switzerland, from September 15-18 (Tuesday to Friday), 2015 - to celebrate its birthday, discuss its present and cook up its future!

We will have several extraordinary presentations, for instance by Bjarne Stroustrup on how to write modern, good C++. The majority will include live discussions with users and all the ROOT developers, in an inviting setting.

Read more

ROOT Version 6.04/00

production release

The ROOT team is proud to announce the release of ROOT 6.04/00 featuring many usability enhancements. Highlights of this release include:

- a new `TFormula` implementation that uses cling
- I/O of C++11 containers
- TTreeCache is now enabled by default to accelerate analyses
- many new beautiful palettes (kBird!) that are optimized against monotonic perceptual ordering

Read more

Patch release 6.02/10 - 2015-06-01

patch release

The patch release of ROOT v6.02/10 is now available.

The Git tag for this version is **v6-02-10**.

For what is fixed in this patch release see the patch release notes; most notably is the support for XCode 6.3.

Read more

Patch release 5.34/30 - 2015-04-23

patch

Preemptive Trouble Shooting

? *What could be the advantage of learning this software technology?*

! **1.** Batteries included: you have all the tools to process, store, analyse and visualise data in one single kit.

! **2.** You join a huge community, O(10^4) users + a very supportive team of core developers

? *Why C++ and not a scripting language?!*

! Performance. Support for languages like Python

? *Why prompt and libraries instead of a GUI?*

! ROOT is a programming framework, not an office suite.

C++ From 10.000 Km

C++ From 10.000 Km

Compiled, strongly typed language, allows to squeeze all the performance out of the hardware

- Veritable federation of languages, including C

Allows object orientation

Allows generic programming

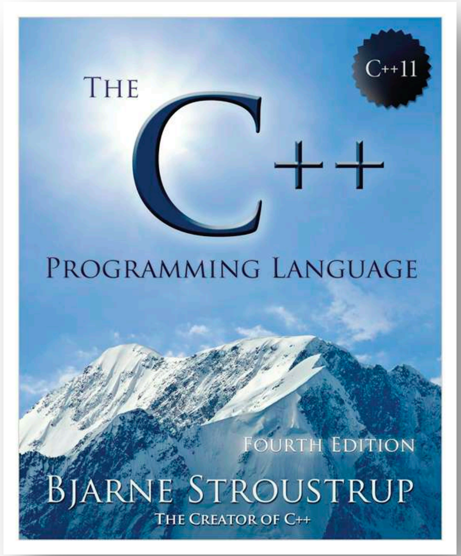
- Templates

Explicit memory management

“Everything is a pointer”

Main language, together with Python, of HEP

- 90s: port ~all legacy FORTRAN HEP code to C++
- Reduce costs of management of large codebases (millions of lines of code)
- Allow groups of hundreds of active developers



Some Useful Terms

- A class is an entity which encapsulate “data” and “actions” on it
- The “data” is represented by the *data members* (“variables of the class”)
- The actions are expressed by the *class methods* (“functions of the class”)
- One *calls*, *invokes* a method which can have zero or more arguments
- An *object* is an instance of a *class*
- An object is created by a special method, the *constructor*. There can be more than one constructor, e.g.:
  - `TH1F histo = TH1F(); // default constructor`
  - `TH1F histo = TH1F(“histName”, “HistTitle”, 64, 0, 64); // with params`

Note: the language is somehow approximate but certainly ok for this lecture

-> and .

The *dot* and *arrow operators* are used to access methods and members of objects and pointers to objects

- *Dot*: to access methods and members of objects
- *Arrow*: to access methods and members of pointers to objects

Example:

```
MyClass myClassInstance(“myName”);
myClassInstance.GetName();
auto myClassInstancePtr = new MyClass (“myName”);
myClassInstancePtr->GetName();
```

Note: the language is somehow approximate but certainly ok for this lecture

ROOT Basics

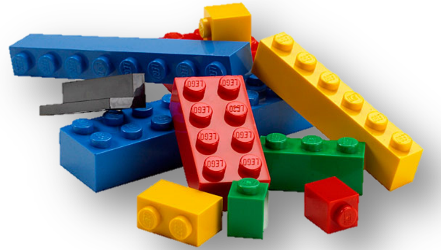
ROOT as a Calculator

ROOT as Function Plotter

Plotting Measurements

Histograms

Interactive ROOT Section



Let’s Fire Up ROOT

The ROOT Prompt

C++ is a compiled language

- A compiler is used to translate source code into machine instructions

ROOT provides a C++ **interpreter**

- Interactive C++, w/o the need of a compiler, like Python, Ruby, Haskell …
- Allows reflection (inspect at runtime layout of classes)
- Can be booted with the command:

```
root
```

- The interactive shell is also called "ROOT prompt" or "ROOT interactive prompt"

ROOT As a Calculator

ROOT interactive prompt can be used as an advanced calculator!

```
root [0] 1+1
(int)2
root [1] 2*(4+2)/12.
(double) 1.000000e+00
root [2] sqrt(3.)
(double) 1.732051e+00
root [3] 1 > 2
(bool) false
```

Try it!

ROOT allows not only to type in **C++ statements**, but also advanced **mathematical functions**, which live in the TMath namespace.

```
root [4] TMath::Pi()
(Double_t) 3.141593e+00
root [5] TMath::Erf(.2)
(Double_t) 2.227026e-01
```

ROOT As a Calculator++

Here we make a step forward.
We Declare **variables** and used
a ***for*** control structure.
Tab-completion available!

```
root [6] double x=.5
(double) 5.000000e-01
root [7] int N=30
(int) 30
root [8] double gs=0
(double) 0.000000e+00
```

```
root [9] for (int i=0;i<N;++i) gs += TMath::Power(x,i)
root [10] TMath::Abs(gs - (1-TMath::Power(x,N-1))/(1-x))
(Double_t) 1.862645e-09
```

Interlude: Controlling ROOT

Special commands which are not C++ can be typed at the prompt, they start with a "."

```
root [1] .<command>
```

For example:

- Quit root: `.q`
- Issue a shell command: `.!<OS_command>`
- Load a macro: `.L <file_name>` (see following slides about macros)
- `.help` or `.?` gives the full list

Exercise

For x values of 0,1,10 and 20 check the difference of the value of a hand-made non-normalised Gaussian and the TMath::Gaus routine.

For one number

```
root [0] double x=0
root [2] exp(-x*x*.5) – TMath::Gaus(x)
[…]
```

Exercise Solution

For x values of 0,1,10 and 20 check the difference of the value of a hand-made non-normalised Gaussian and the TMath::Gaus routine.

```
root [0] double x=0
root [2] exp(-x*x*.5) – TMath::Gaus(x)
[…]
```

Many possible ways of solving this! E.g:

```
root [0] for (auto v : {0.,1.,10.,20.}) cout << v << “ ” << exp(-
x*x*.5) – Tmath::Gaus(x) << endl
```

ROOT As a Function Plotter

The class TF1 represents one dimensional functions (e.g. *f(x)*):

```
root [0] TF1 f1("f1","sin(x)/x",0.,10.);//name,formula, min, max
root [1] f1.Draw();
```

An extended version of this example is the definition of a function with parameters:

```
root [2] TF1 f2("f2","[0]*sin([1]*x)/x",0.,10.);
root [3] f2.SetParameters(1,1);
root [4] f2.Draw();
```

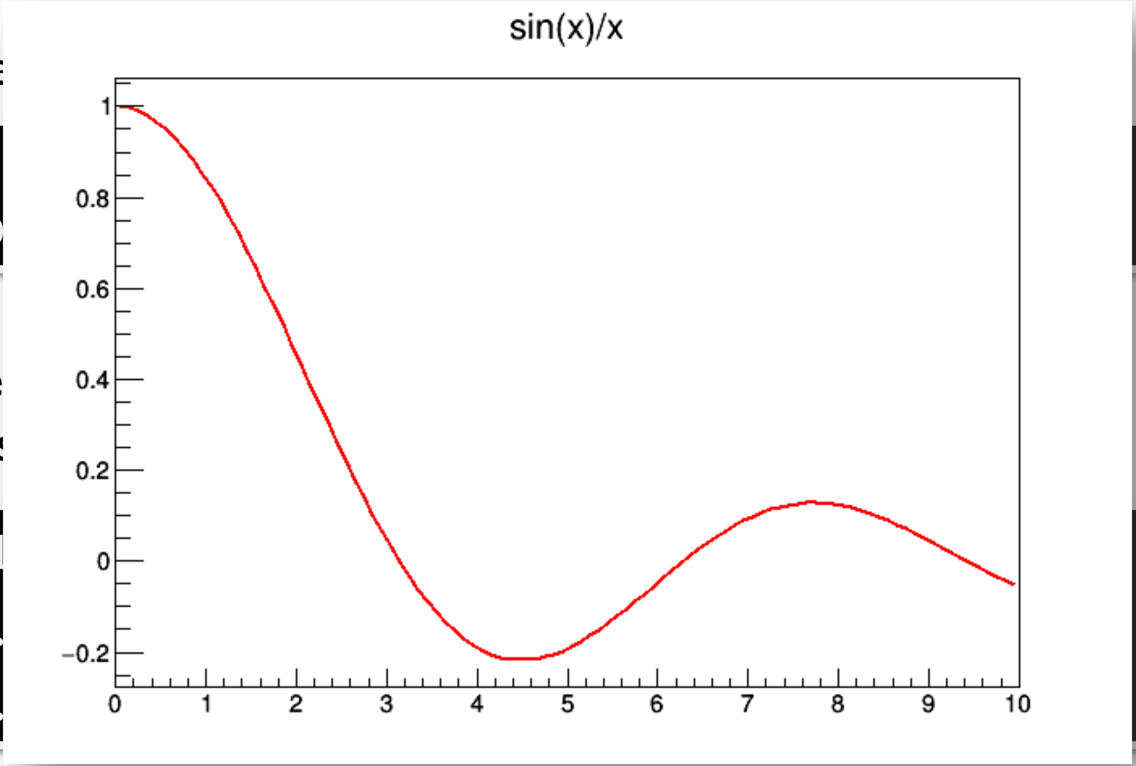
ROOT As a Function Plotter

The class TF1 re

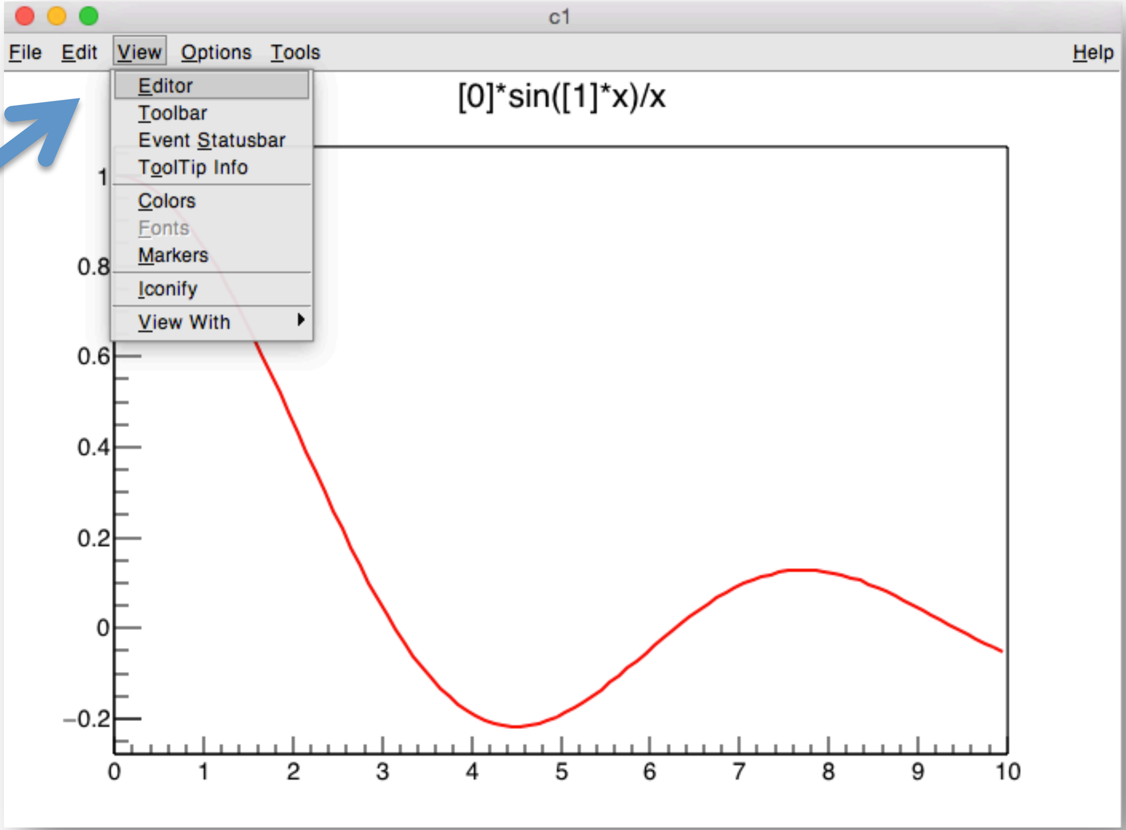
```
root [0] TF1                                              min, max
root [1] f1.D
```

An extended ve
with parameter

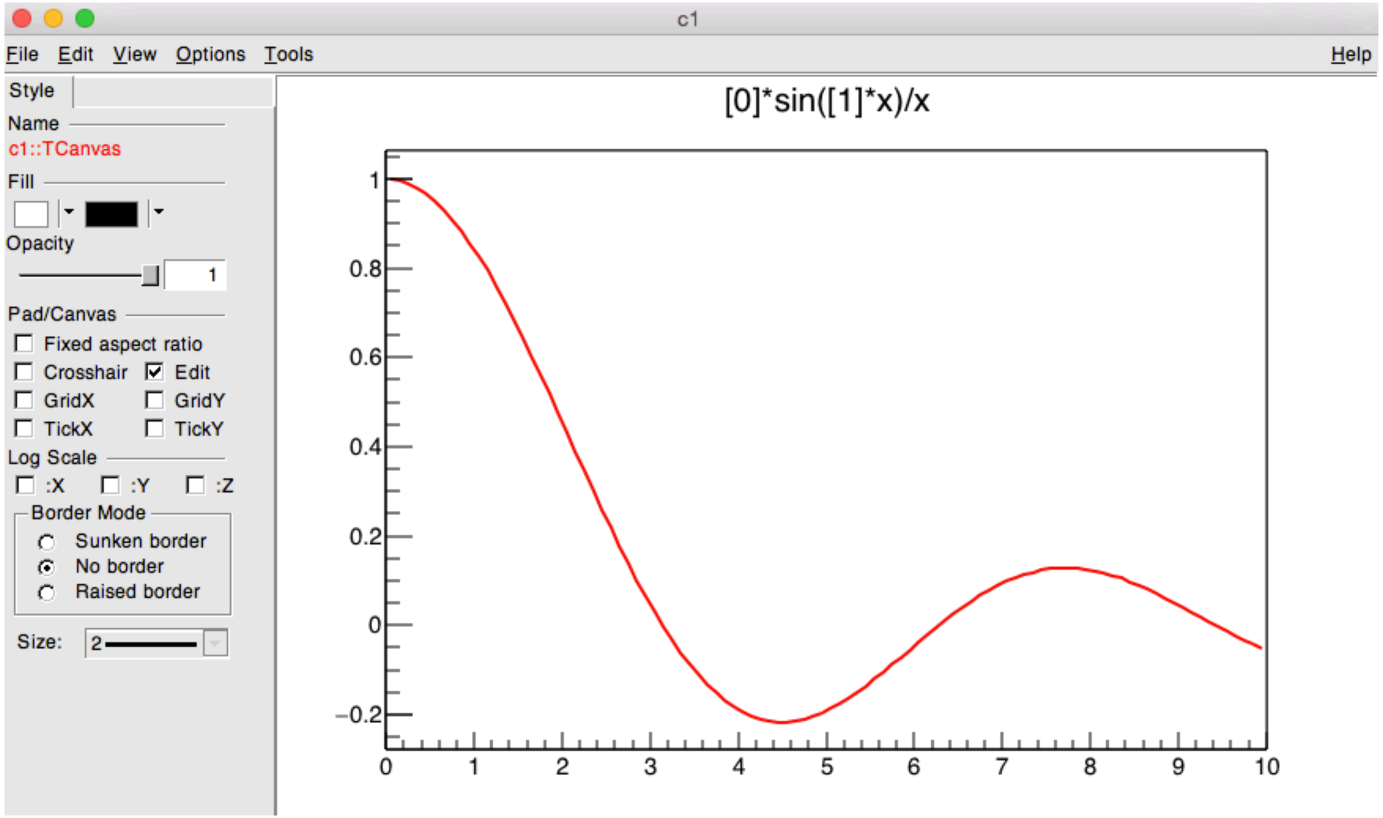
```
root [2] TF1
root [3] f2.
root [4] f2.
```



Exercise: Interaction With The Plot

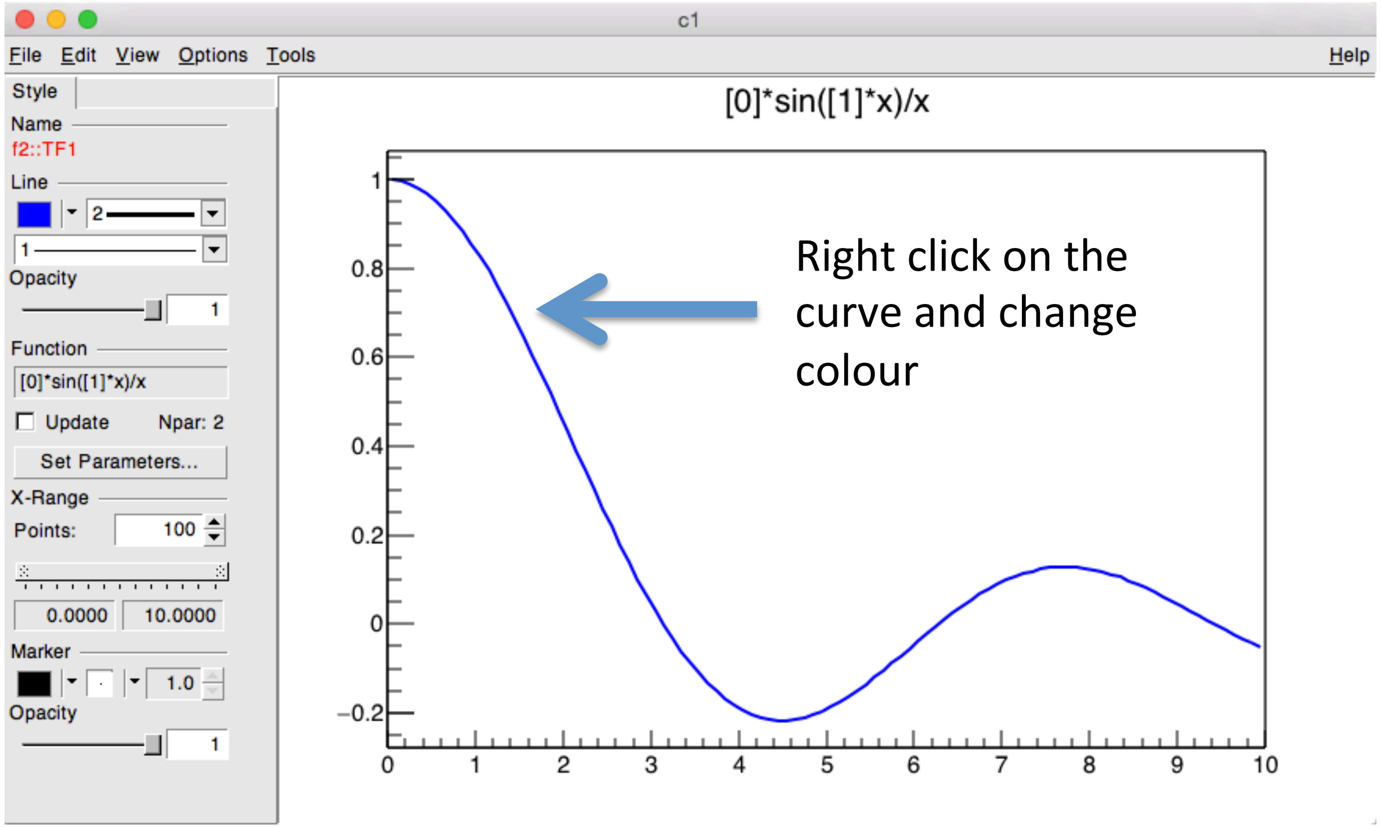


Exercise: Interaction With The Plot



☐ Fixed aspect ratio
☐ Crosshair ☑ Edit
☐ GridX ☐ GridY
☐ TickX ☐ TickY
Log Scale: ☐ :X ☐ :Y ☐ :Z
Border Mode: Sunken border [✓ No border] Raised border
Size: 2

Exercise: Interaction With The Plot



Name: f2::TF1

Line: 2, 1

Opacity: 1

Function: [0]*sin([1]*x)/x

Update Npar: 2

Points: 100

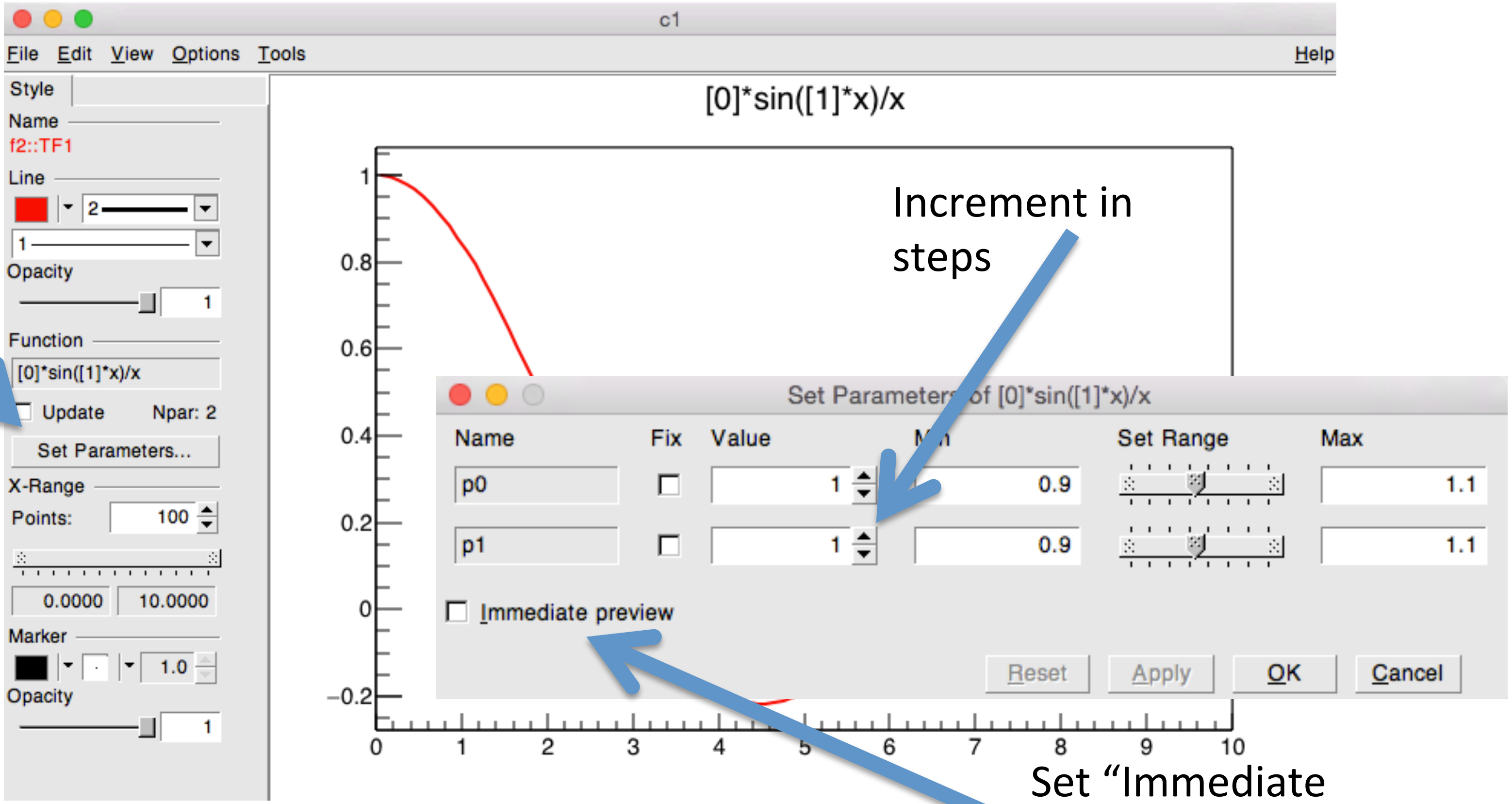
0.0000 10.0000

Marker: 1.0

Opacity: 1

Right click on the curve and change colour

Exercise: Interaction With The Plot

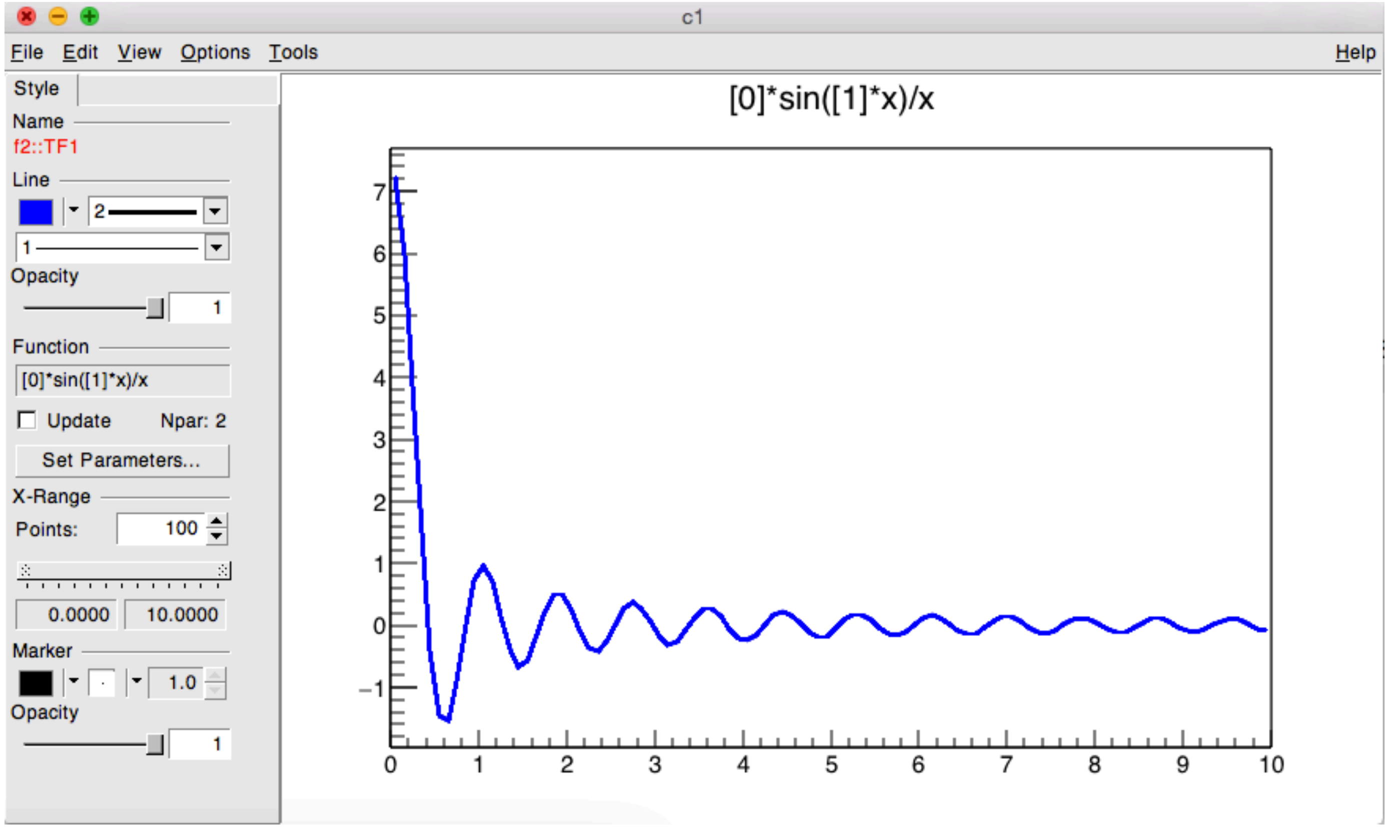


Name	Fix	Value	Min	Set Range	Max
p0	☐	1	0.9		1.1
p1	☐	1	0.9		1.1

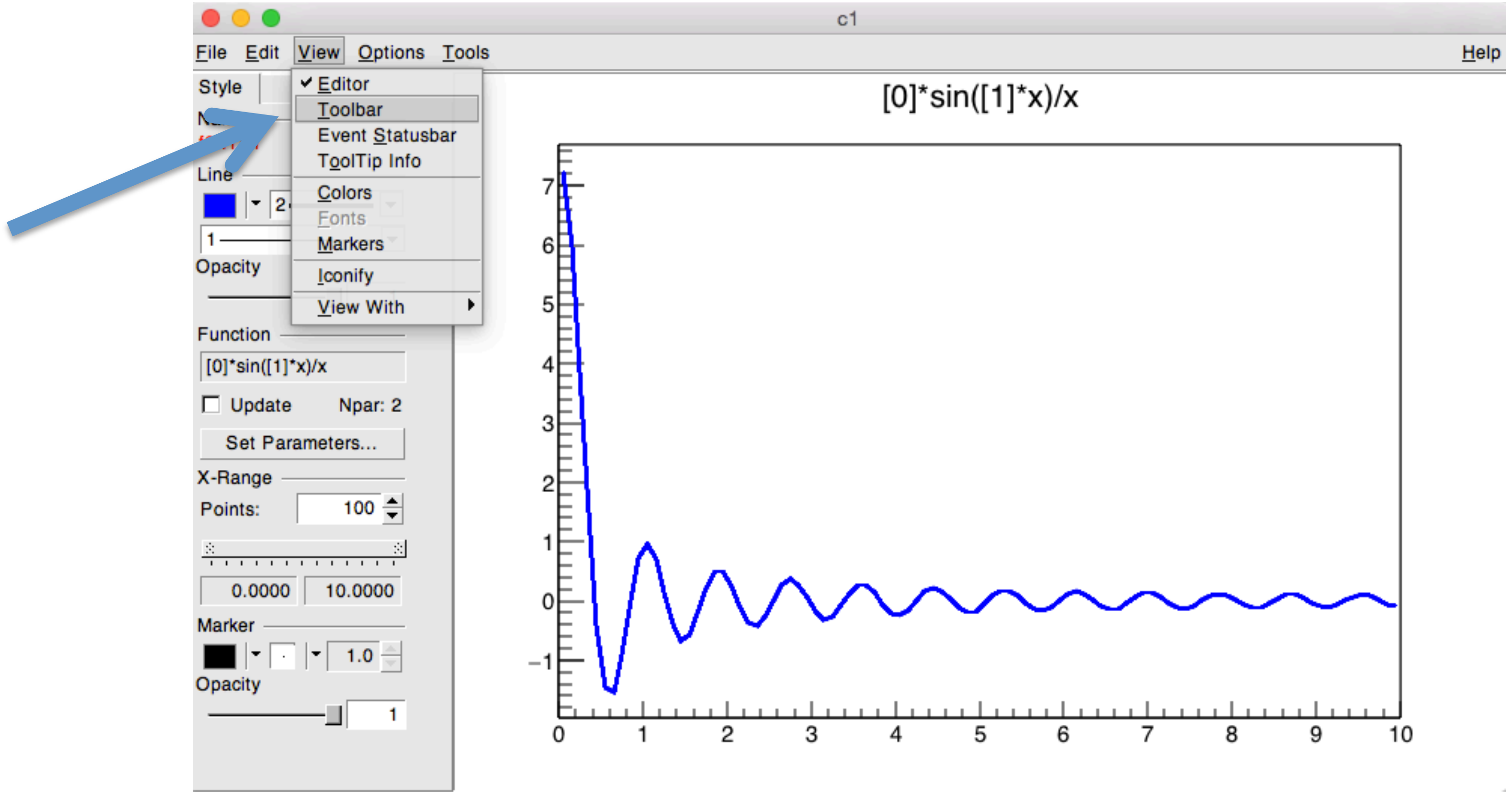
Increment in steps

Set “Immediate preview”

Exercise: Interaction With The Plot



Exercise: Interaction With The Plot



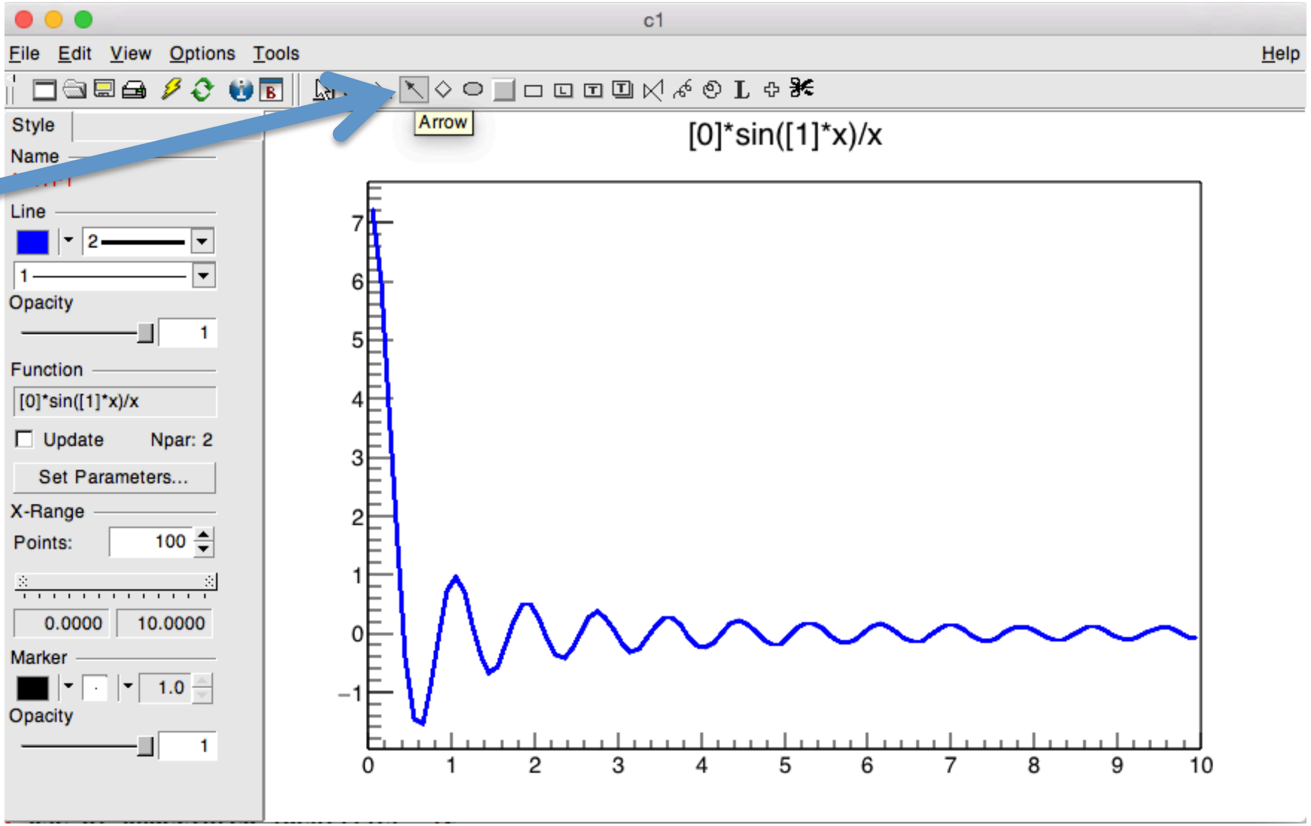
[0]*sin([1]*x)/x

Npar: 2

Points: 100

0.0000 10.0000

Exercise: Interaction With The Plot



Style

Name

Line

2

1

Opacity 1

Function

[0]*sin([1]*x)/x

☐ Update Npar: 2

Set Parameters...

X-Range

Points: 100

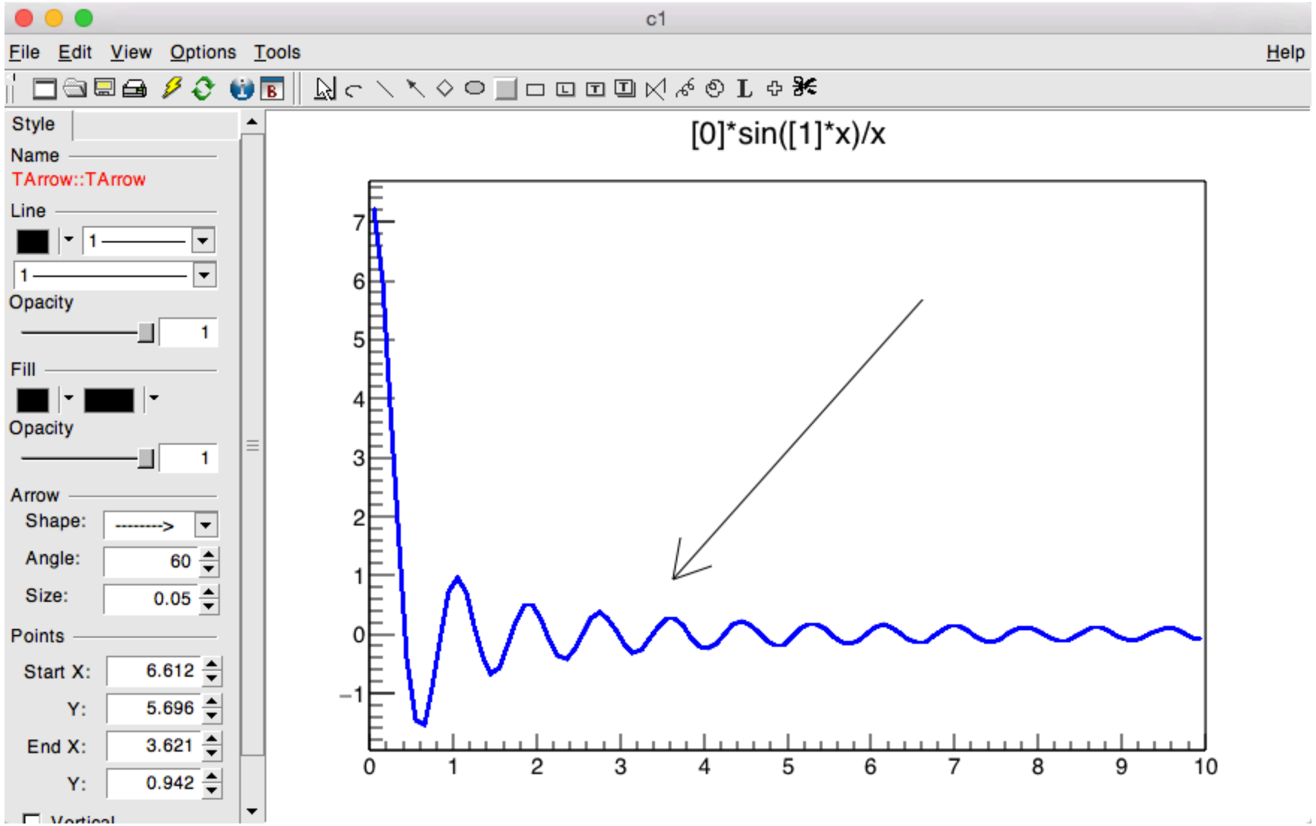
0.0000 10.0000

Marker

1.0

Opacity 1

Exercise: Interaction With The Plot



Style

Name
TArrow::TArrow

Line
1
1
Opacity 1

Fill
Opacity 1

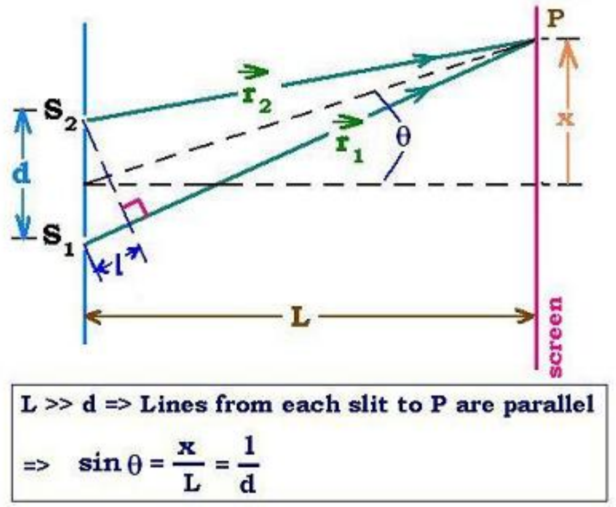
Arrow
Shape: -------->
Angle: 60
Size: 0.05

Points
Start X: 6.612
Y: 5.696
End X: 3.621
Y: 0.942

☐ Vertical

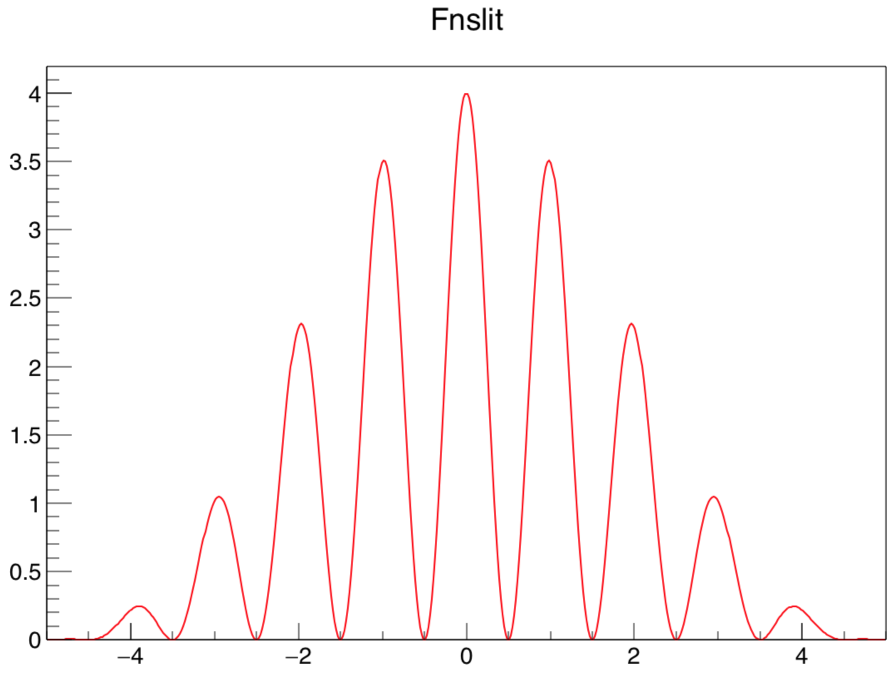
ROOT As a Function Plotter

The example **slits.C** characterised in the Primer, is a more complex C++ program calculating and displaying the interference pattern produced by light falling on a multiple slit.



L >> d => Lines from each slit to P are parallel

$$\Rightarrow \quad \sin\theta = \frac{x}{L} = \frac{l}{d}$$



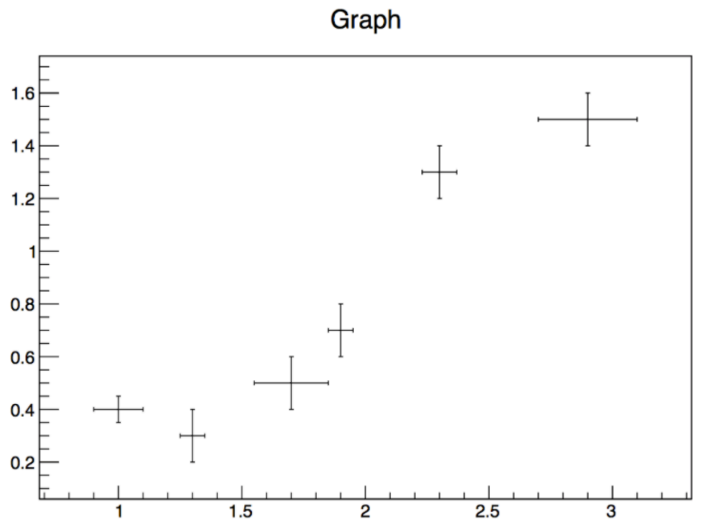
Slits_cpp

Plotting Measurements

The class `TGraphErrors` allows to display measurements in ROOT, including errors, with different types of constructors. In the following example, data are taken from the file `ExampleData.txt`:

```
root [0] TGraphErrors gr("ExampleData.txt");
root [1] gr.Draw("AP");
```

Tells ROOT to draw the **A**xis and the **P**oints



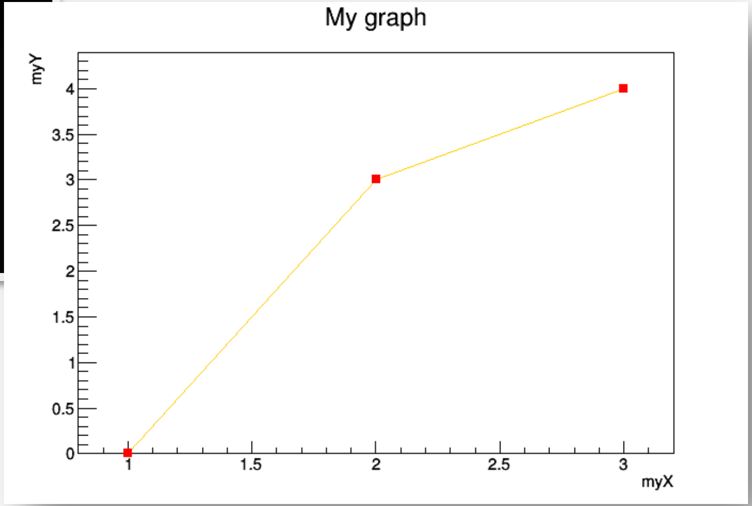
Extempore Exercise

- Create a graph (TGraph)
- Set its title to “My graph”, its X axis title to “myX” and Y axis title to “myY”
- Fill it with three points: (1,0), (2,3), (3,4)
- Set a red full square marker
- Draw a orange line between points

Let’s solve this together at the whiteboard!

Exercise Solution

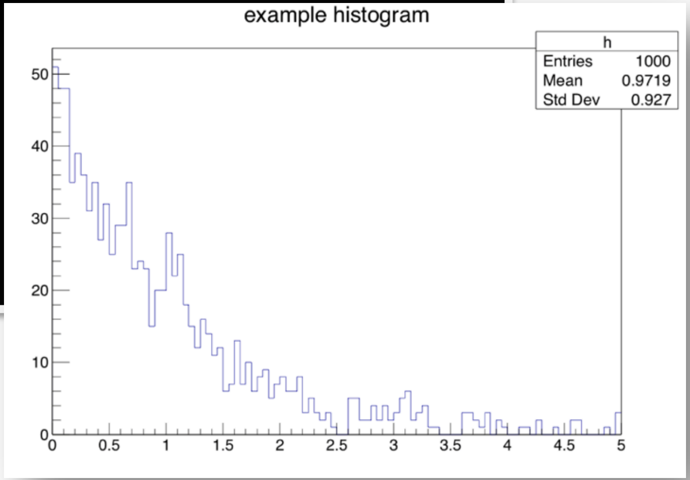
```
root [0] TGraph g
root [1] g.SetTitle("My graph;myX;myY")
root [2] g.SetPoint(0,1,0)
root [3] g.SetPoint(1,2,3)
root [4] g.SetPoint(2,3,4)
root [5] g.SetMarkerStyle(kFullSquare)
root [6] g.SetMarkerColor(kRed)
root [7] g.SetLineColor(kOrange)
root [8] g.Draw("APL")
```



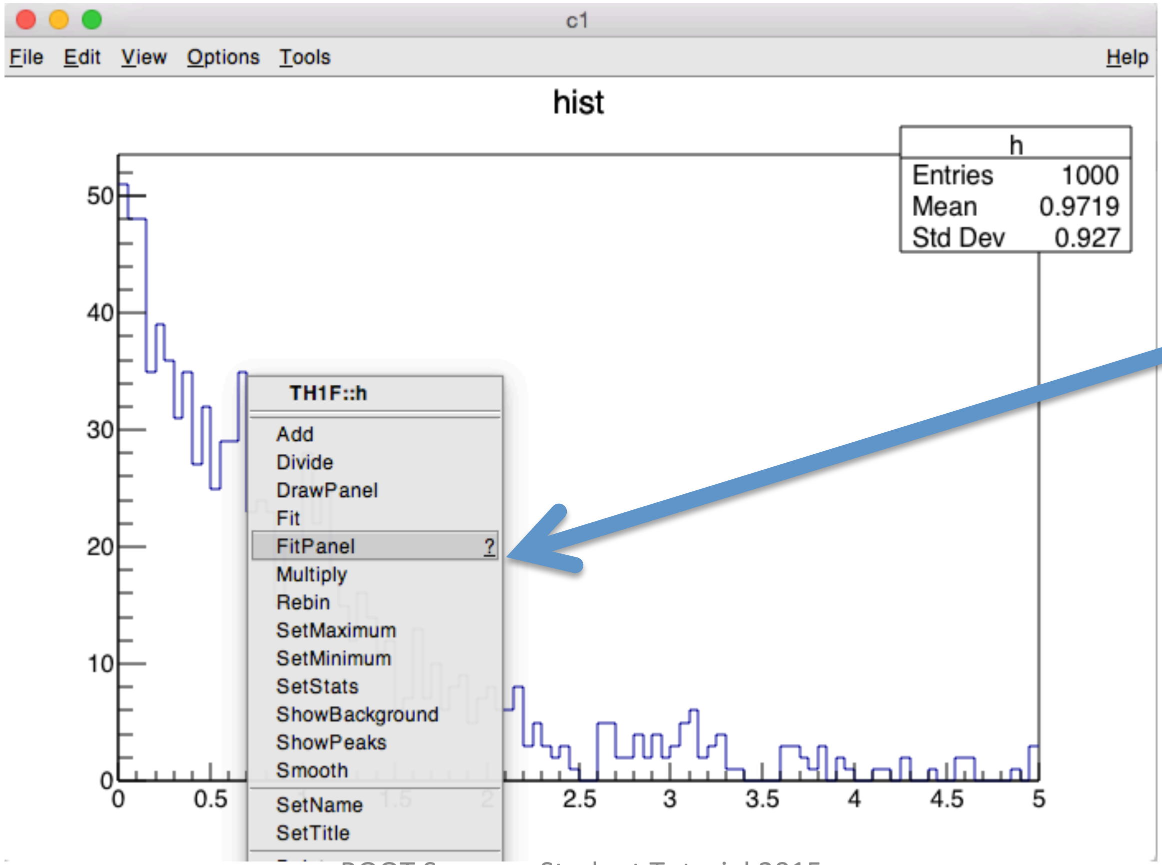
Histograms

- In ROOT, the TH* classes represent histograms
- TH1* are monodimensional, TH2* are bidimensional …
- The final letter describes the type stored in each bin:
  A double in TH1D, a float in TH1F …

```
root [0] TF1 efunc("efunc","exp([0]+[1]*x)",0.,5.)
root [1] efunc.SetParameters(1,-1)
root [2] TH1F h("h","hist",100,0.,5.)
root [3] for (int i=0;i<1000;i++)
h.Fill(efunc.GetRandom())
root [4] h.Draw()
```

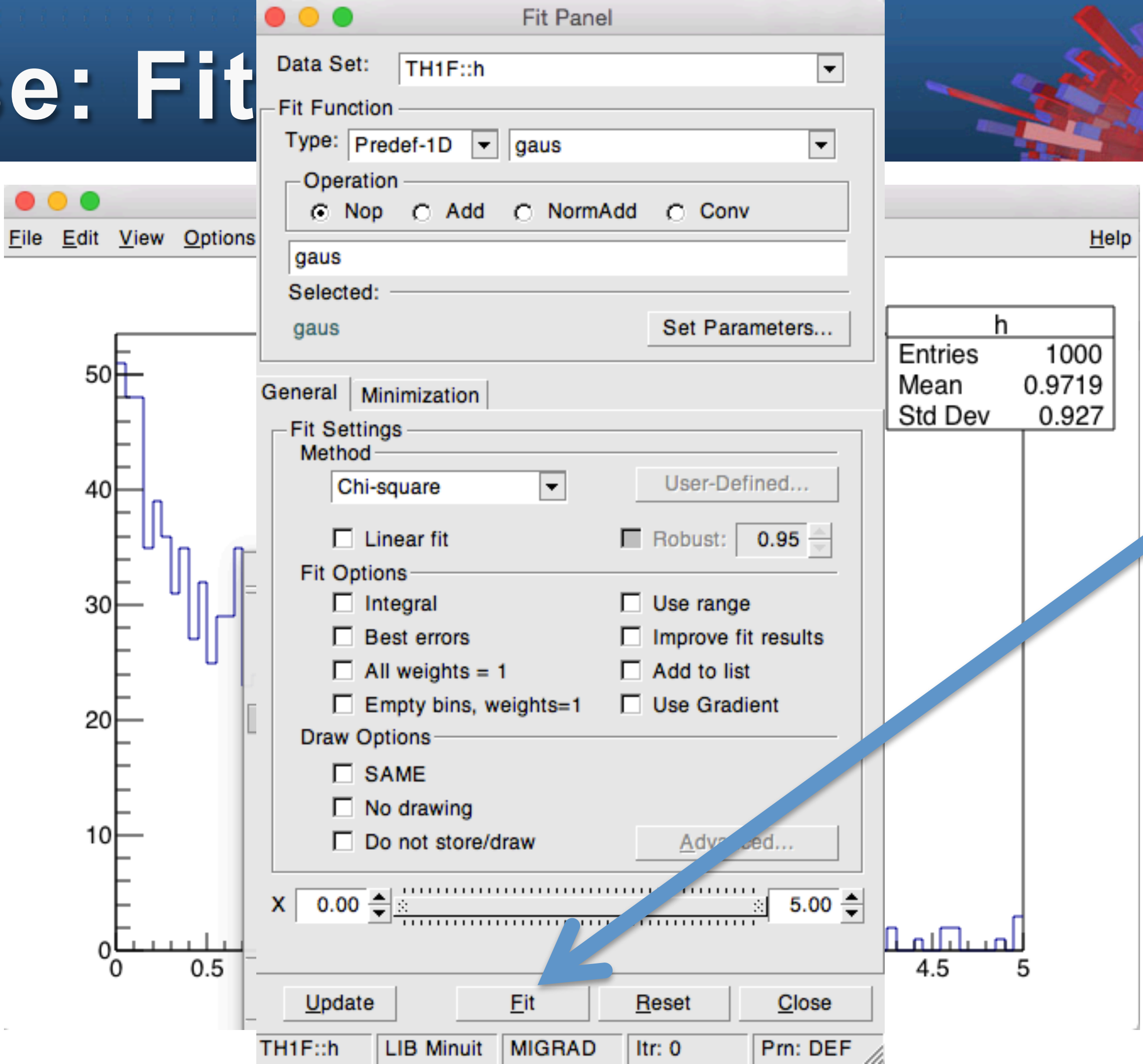


All together: Fitpanel



Click on the histogram “line”

Exercise: Fit



Data Set: TH1F::h

Fit Function

Type: Predef-1D | gaus

Operation: [✓ Nop] Add NormAdd Conv

gaus

Selected: gaus

Fit Settings

Method: Chi-square

☐ Linear fit   ☐ Robust: 0.95

Fit Options

☐ Integral   ☐ Use range
☐ Best errors   ☐ Improve fit results
☐ All weights = 1   ☐ Add to list
☐ Empty bins, weights=1   ☐ Use Gradient

Draw Options

☐ SAME
☐ No drawing
☐ Do not store/draw

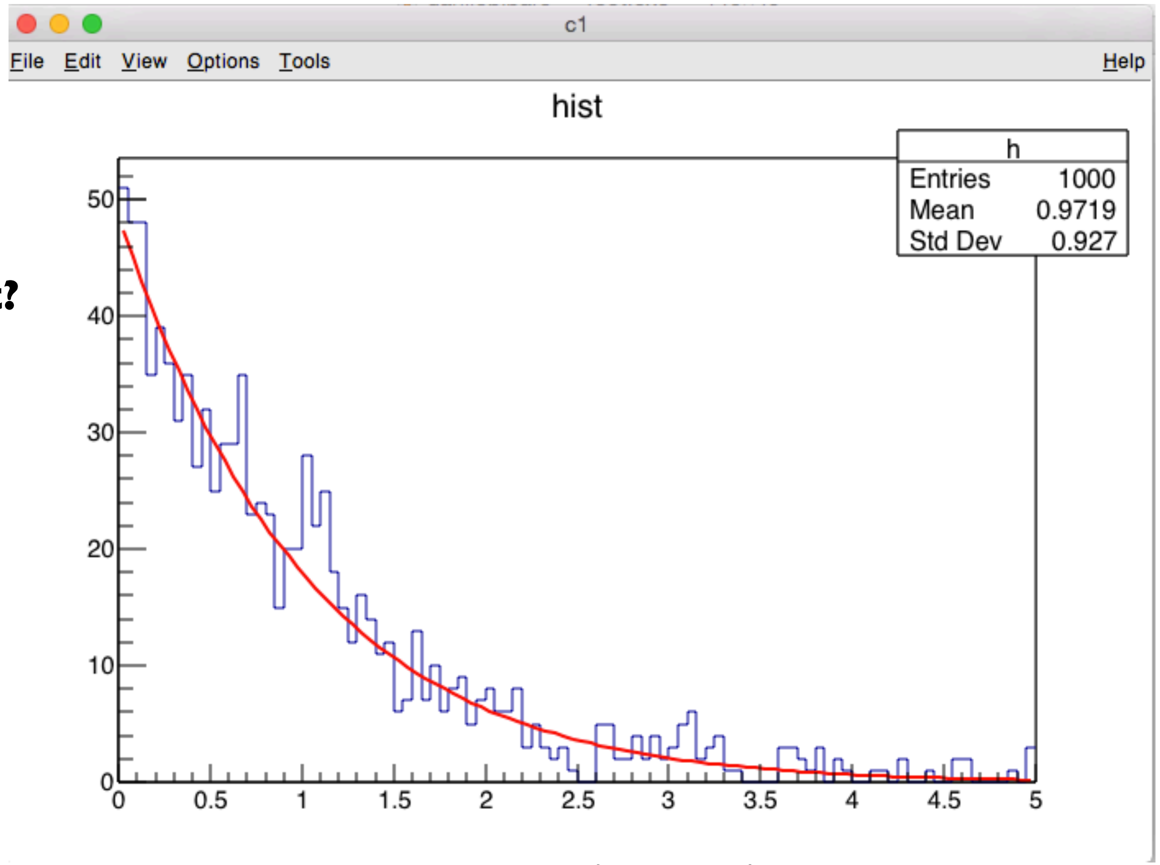
X 0.00 – 5.00

TH1F::h | LIB Minuit | MIGRAD | Itr: 0 | Prn: DEF

Fit!

Exercise: Fitpanel

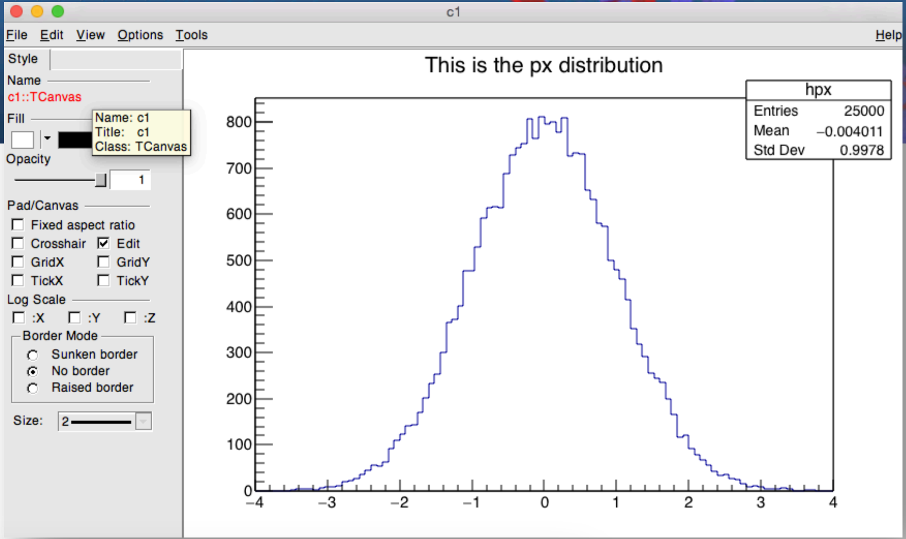
Is this a good fit? Why?



h	
Entries	1000
Mean	0.9719
Std Dev	0.927

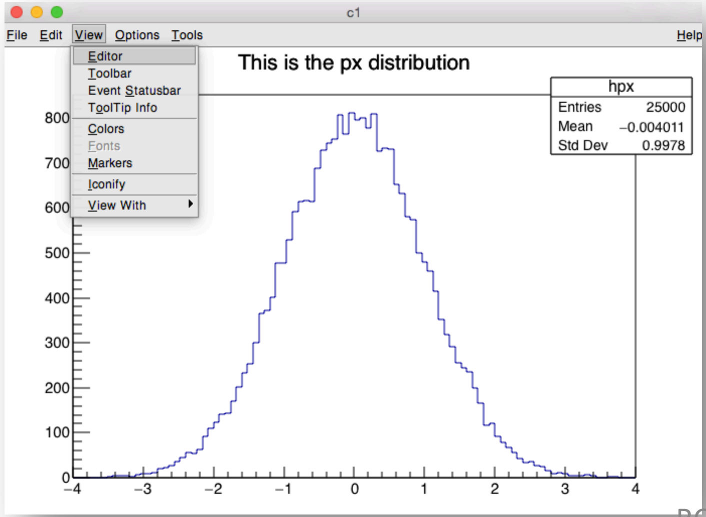
Interactive ROOT

Look at one of your plots again and move the mouse across.
You will notice that this is much more than a static picture !
You can interact with objects and manipulate them. **Try it !!**

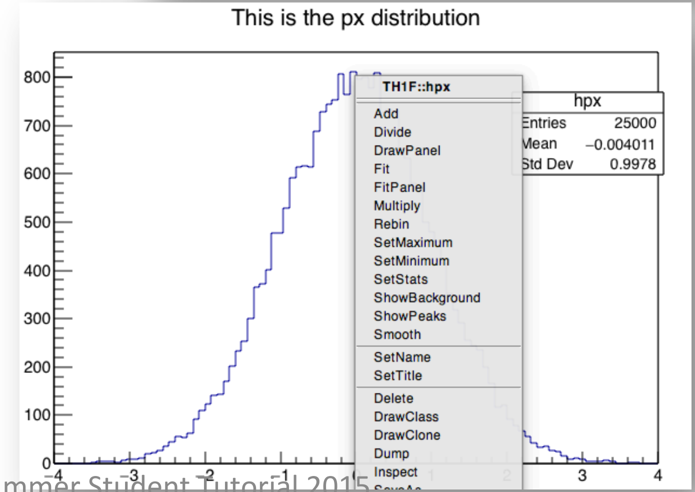

c1
File Edit View Options Tools Help
This is the px distribution
800
700
600
500
400
300
200
100
0
−4 −3 −2 −1 0 1 2 3 4

Style
Name c1::TCanvas
Name: c1
Title: c1
Class: TCanvas
Fill
Opacity 1
Pad/Canvas
[ ] Fixed aspect ratio
[ ] Crosshair [✓ Edit]
[ ] GridX [ ] GridY
[ ] TickX [ ] TickY
Log Scale
[ ] :X [ ] :Y [ ] :Z
Border Mode
( ) Sunken border
[✓ No border]
( ) Raised border
Size: 2

hpx	
Entries	25000
Mean	−0.004011
Std Dev	0.9978



hpx	
Entries	25000
Mean	−0.004011
Std Dev	0.9978



hpx	
Entries	25000
Mean	−0.004011
Std Dev	0.9978

ROOT Macros

General Remarks

A more complete example

Summary of Visual effects

Interpretation and Compilation

General Remarks

We have seen how to interactively type lines at the prompt.
The next step is to write "ROOT Macros" – lightweight programs
The general structure for a macro stored in file *MacroName.C* is:

Function, no main,
same name as the file

```
void MacroName() {
        <             ...
            your lines of C++ code
                      ...               >
}
```

Running a Macro

The macro is executed at the system prompt by typing:

```
> root MacroName.C
```

or executed at the ROOT prompt using .x:

```
> root
 root [0] .x MacroName.C
```

or it can be loaded into a ROOT session and then be executed by typing:

```
root [0].L MacroName.C
root [1] MacroName();
```

A More Complex Example

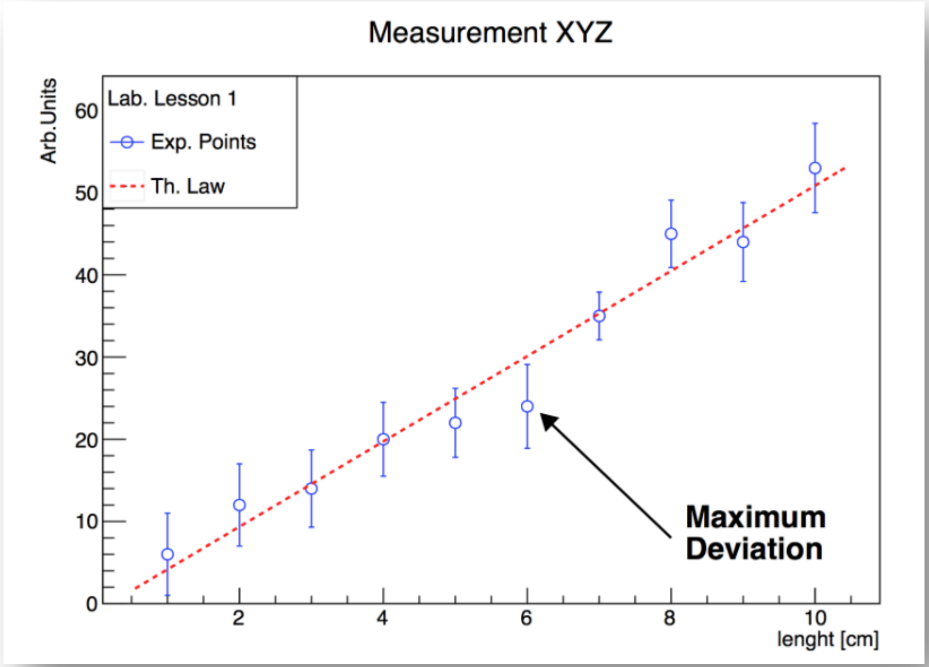
The example in section 3.2 of the ROOT primer, is a typical task in data analysis, a macro that constructs a graph with errors, fits a (linear) model to it and saves it as an image.

Let's inspect it together.

A More Complex Example

And Run it!

```
> root macro1.C
```



Macro1_cpp

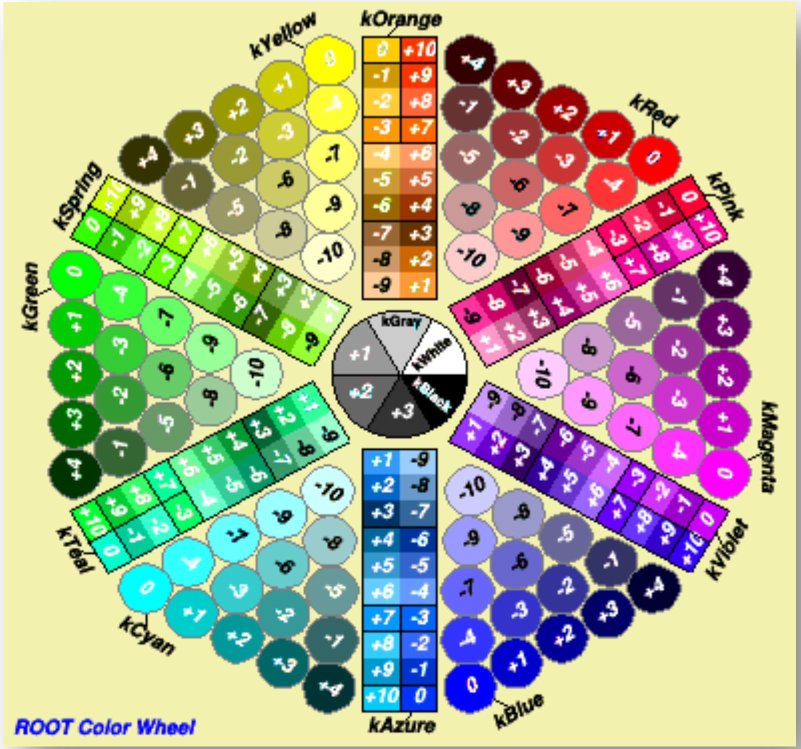
Summary of Visual Effects

- **Colours and Graph Markers:** To specify a colour, some identifiers like kWhite, kRed or kBlue can be used for markers, lines, arrows etc. The complete summary of colours is represented by the ROOT "colour wheel". ROOT provides several graphics markers like triangles, crosses or stars.

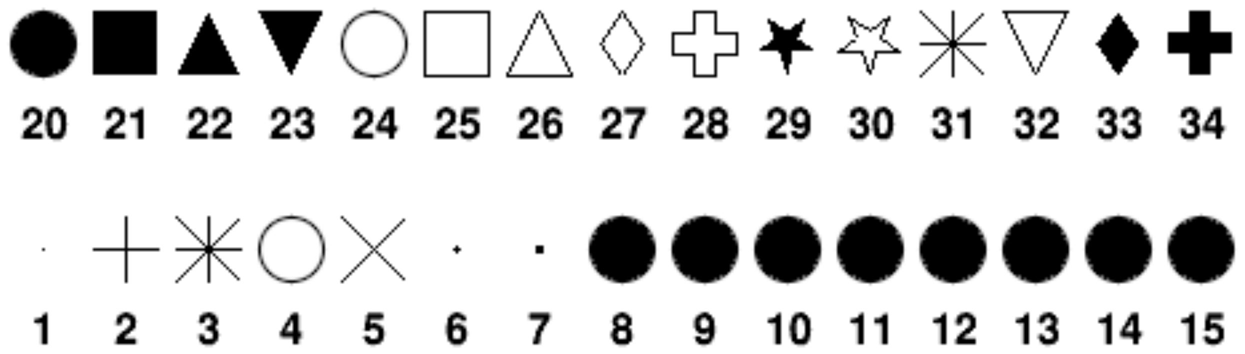
- **Arrows and Lines:** The class representing arrows is TArrow, which inherits from TLine. The constructors of lines and arrows always contain the coordinates of the endpoints.

- **Text:** A possibility to add text in plots is provided by the TLatex class. Latex mathematical symbols are automatically interpreted, you just need to replace the "\" by a "#".

TColorWheel



The Family of Markers



```
kDot=1, kPlus, kStar, kCircle=4, kMultiply=5,
kFullDotSmall=6, kFullDotMedium=7, kFullDotLarge=8,
kFullCircle=20, kFullSquare=21, kFullTriangleUp=22,
kFullTriangleDown=23, kOpenCircle=24, kOpenSquare=25,
kOpenTriangleUp=26, kOpenDiamond=27, kOpenCross=28,
kFullStar=29, kOpenStar=30, kOpenTriangleDown=32,
kFullDiamond=33, kFullCross=34
```

Also available through more friendly names ☺

Interpretation and Compilation

We have seen how ROOT interprets and "just in time compiles" code. ROOT also allows to compile code "traditionally". At the ROOT prompt:

```
root [1] .L macro1.C+
root [2] macro1()
```

Generate shared library and execute function

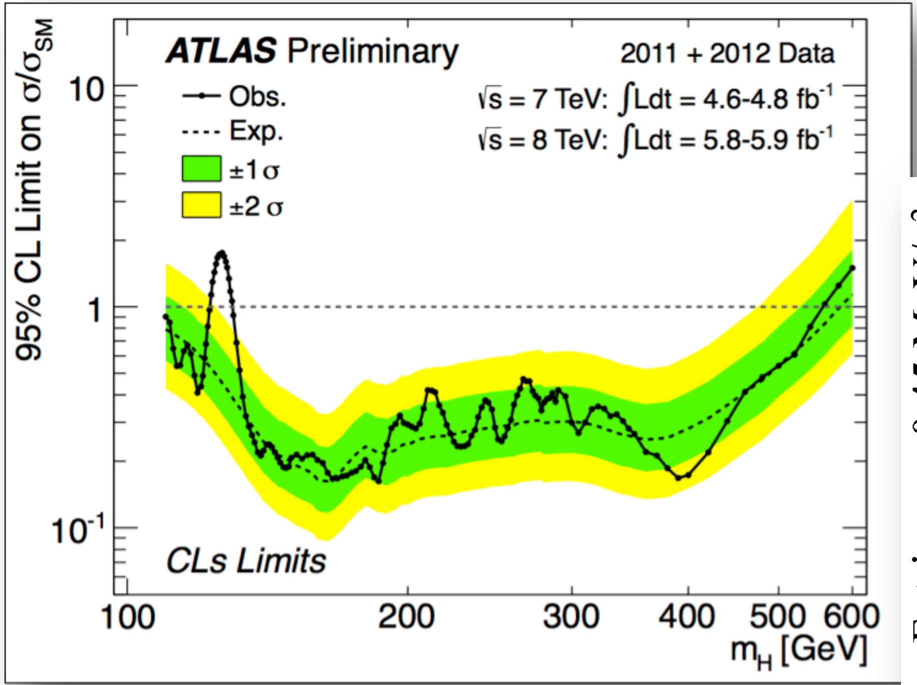
ROOT libraries can be also used to produce standalone, compiled applications:

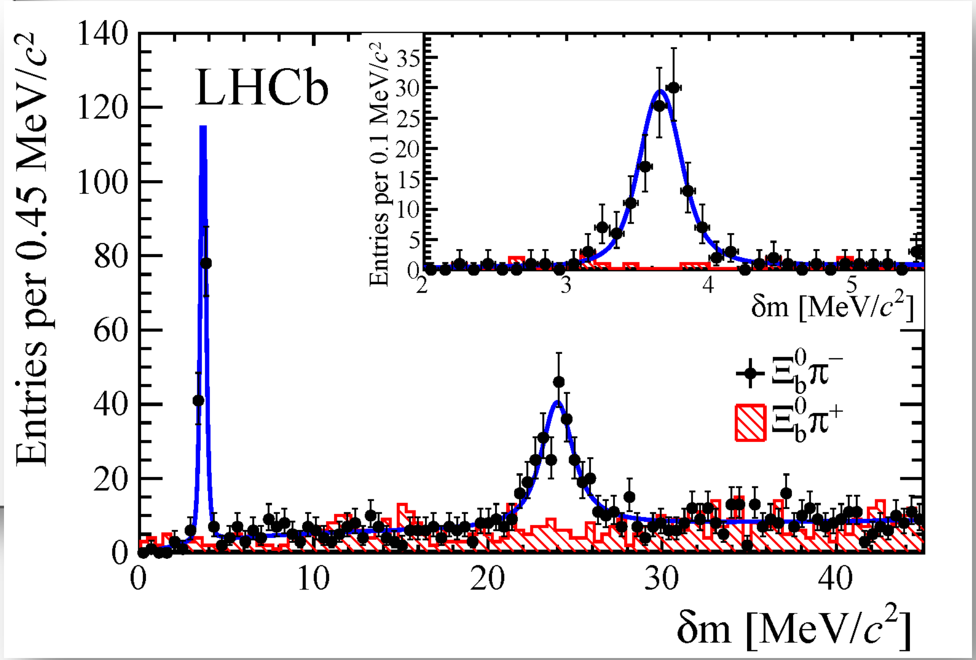
ExampleMacro.C

```
int main() {
  ExampleMacro();
  return 0;
}
```

```
> g++ -o ExampleMacro ExampleMacro.C `root-config --cflags --libs`
> ./ExampleMacro
```

More about Graphs and Histograms





Graphs

Read Graph Points from File

Polar Graphs

2D Graphs

Multiple graphs

From an ASCII File

To build a graph, experimental data can be read from an ASCII file (i.e. standard text) using this constructor:

```
TGraphErrors(const char *filename,
             const char *format="%lg %lg %lg %lg",
             Option_t *option="");
```

Let's have a look to macro2.C (section 4.1 in the Primer).

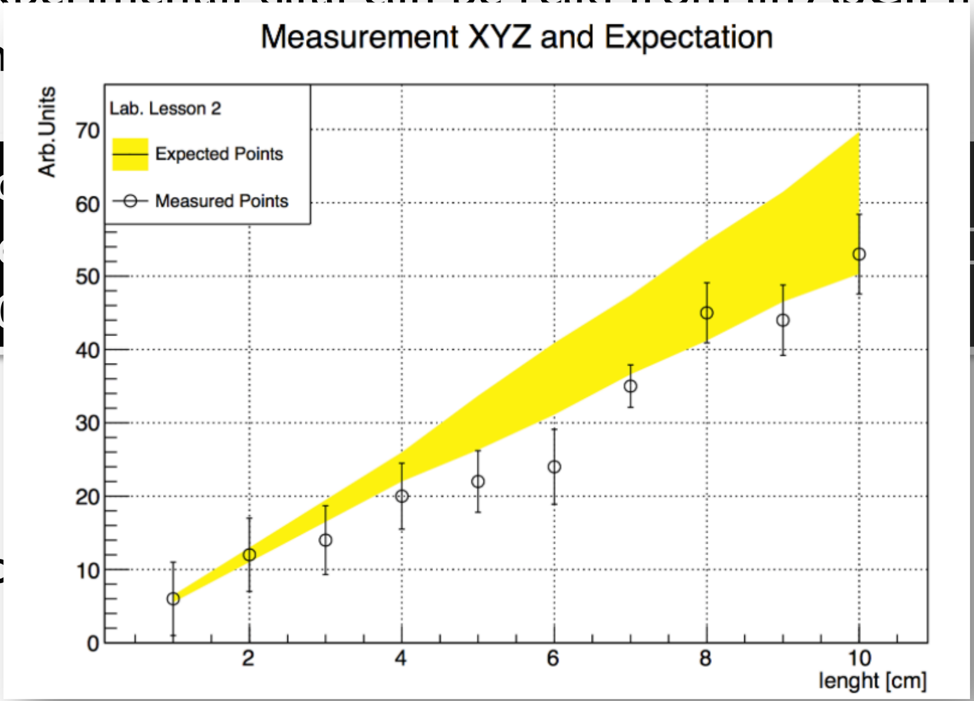
Macro2_cpp

From an ASCII File

To build a graph, experimental data can be read from an ASCII file (i.e. standard text) using this con

```
TGraphErrors(c
             c                                   lg",
             (
```

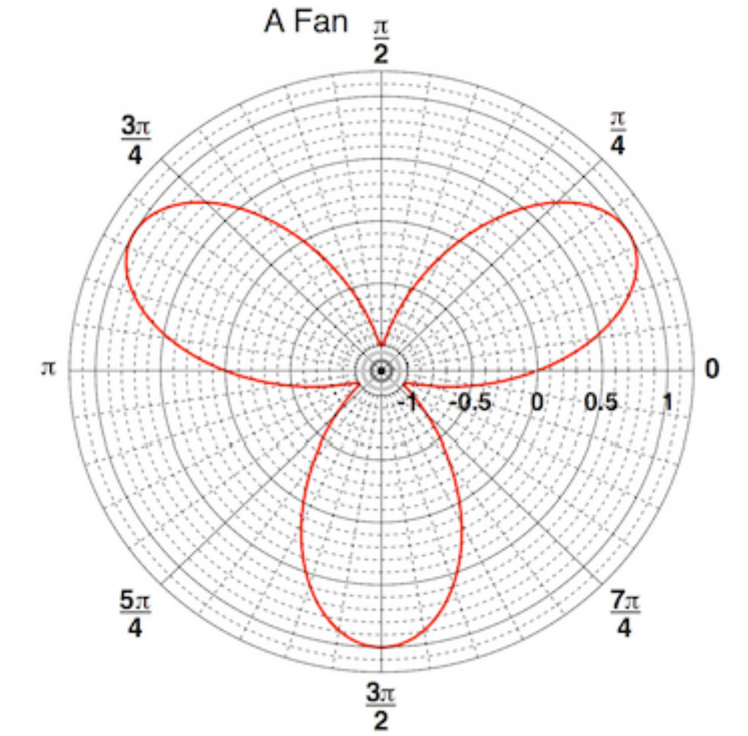
Let's have a look to



Macro2_cpp

Polar Graphs

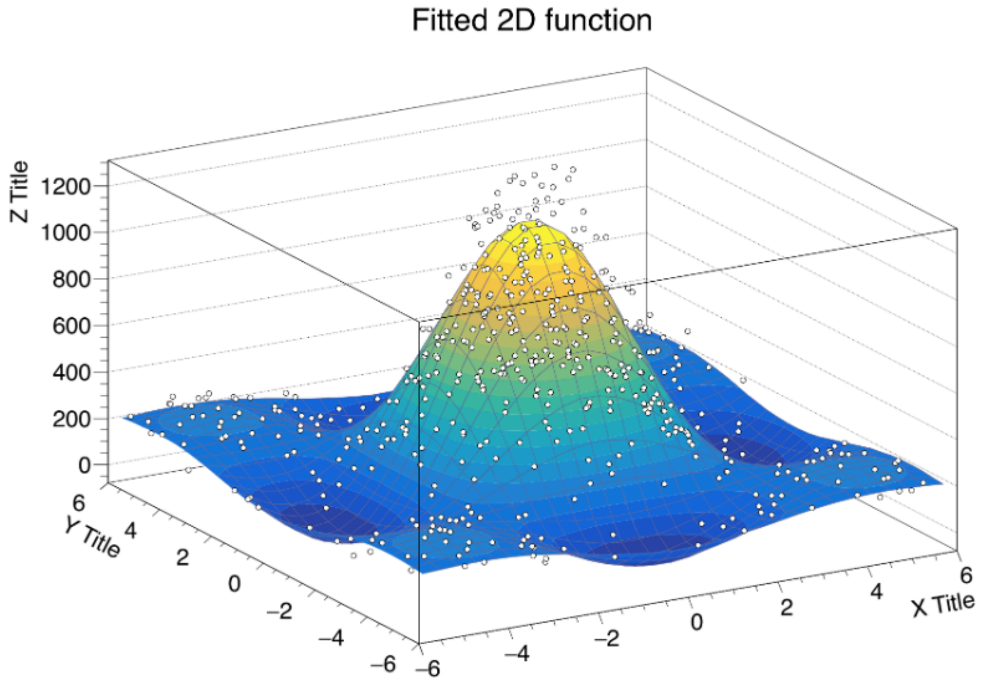
Graphs can also be displayed in polar coordinate like in *macro3.C* (section 4.2 in the Primer):



Macro3_cpp

2D Graphs

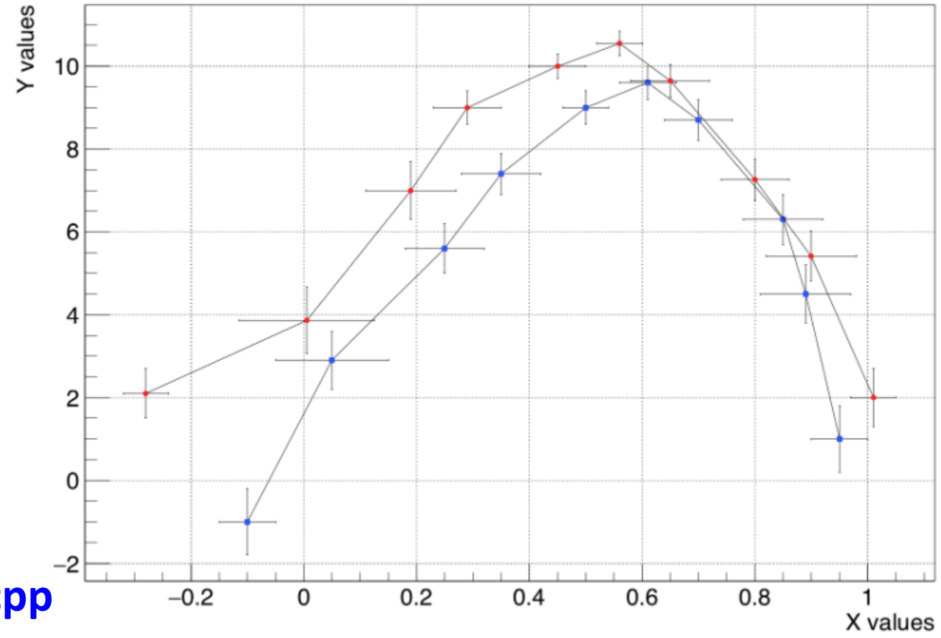
Bi-dimensional graphs can be created in ROOT with the *TGraph2DErrors* class. *macro4.C*, described in Primer's section 4.3, gives a nice example:



Macro4_cpp

Multiple Graphs

It is sometimes useful to group graphs in a single entity, for instance to compute a common axis system. The class *TMultiGraph* described in section 4.4 of the Primer allows that.



Multigraph_cpp

Histograms

Your First (well second!) Histogram

Add and Divide Histograms

Two-dimensional Histograms

Multiple Histograms

Exercise

Write a macro to visualise a Poisson distribution in a histogram

- Create a 1D histogram the bins of which are double precision numbers
- The max number of counts collected is 15 (max value on the x axis)
- Use a random generator to generate 1000 Poissonian counts, mu=4
- Properly set the title and axes names, fill the histogram in blue
- Fit it, programmatically or with the fit panel (right click on the histogram)

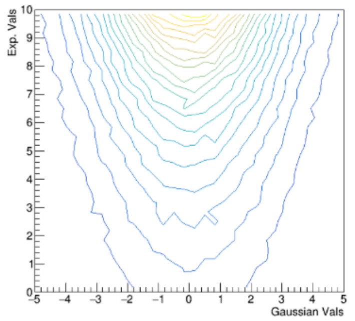
Exercise - Optional

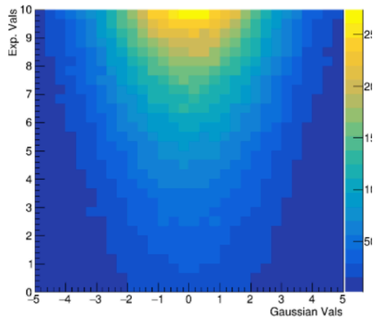
Create a macro that draws the sum, difference and ratio of two histograms

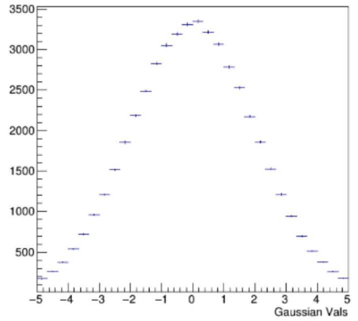
- Create three pairs of histograms, fill them randomly with normally distributed numbers (`TH1::FillRandom(“gaus”)`)
- Divide, sum and subtract them
  - Useful methods:
    `TH1::Divide(const TH1*)`,
    `TH1::Add(const TH1*, Double_t)` the second parameter is a weight
- Nota bene: for every plot a different canvas has to be created and before drawing, one has to “cd” into it
  - `TCanvas c; c.cd();`

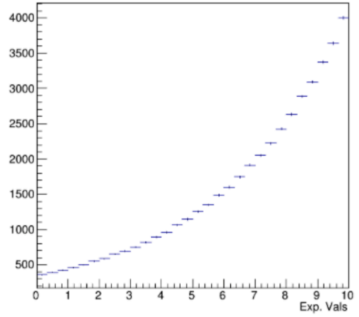
Two Dimensional Histograms

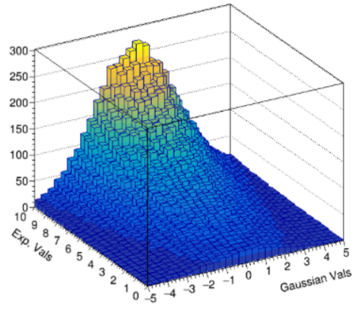
Two-dimensional histograms are a very useful tool, for example to inspect correlations between variables, as in the example in section 5.3 of the Primer:

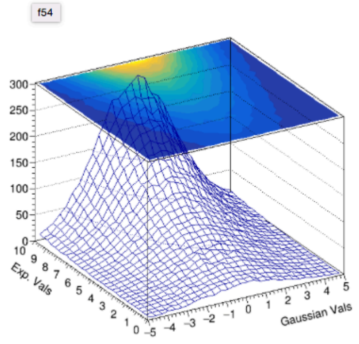


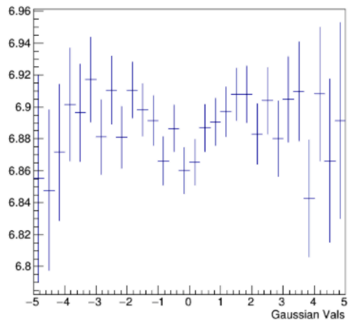


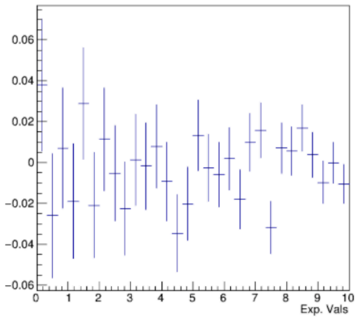








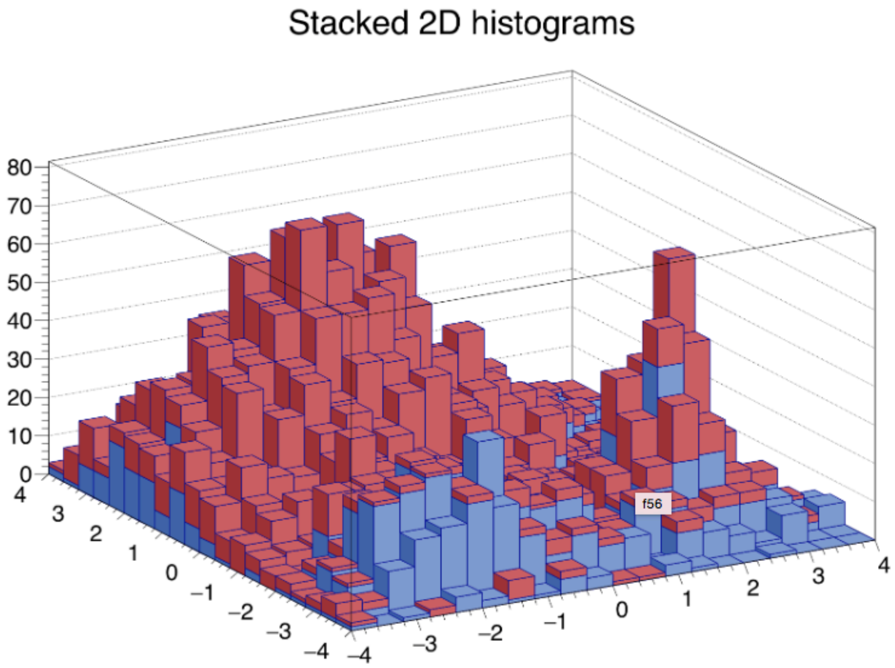




Multiple Histograms

The example in section 5.4 shows how to group histograms in a single entity call a "stack".

Class THStack



THStack_cpp

Input and Output

Storing Objects

N-tuples

Storing Objects in a File

- ROOT allows to store C++ objects on disk (natively the language cannot)
- All ROOT objects* can be written on disk via the `Write` method
    - In general, all instances of classes with dictionaries**
- Two ways of storing: row wise and column wise
    - Single object dump and N-tuple like storage respectively
- Feature widely used, e.g. by all LHC experiments

* All objects which are instances of classes inheriting from `TObject`
** This discussion is beyond the scope of this lecture

An Example

```
TFile out_file("my_rootfile.root","RECREATE"); // Open a Tfile
TH1F h("my_histogram","My Title;X;# of entries",100,-5,5);
h.FillRandom("gaus");
h.Write(); // Write the histogram in the file
out_file.Close(); // Close the file
```

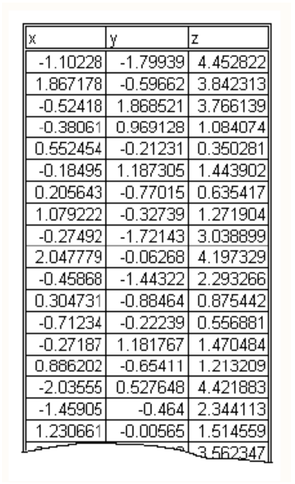
Exercise

Inspect the content of a file with the `TBrowser`

- Create a file copying the lines of the previous slide at the prompt
- Quit the command line interpreter
- Boot ROOT opening the file: `root my_rootfile.root`
- Type: `TBrowser myBrowser`
- Inspect the content of the file

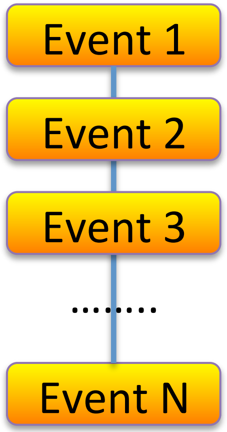
Trees

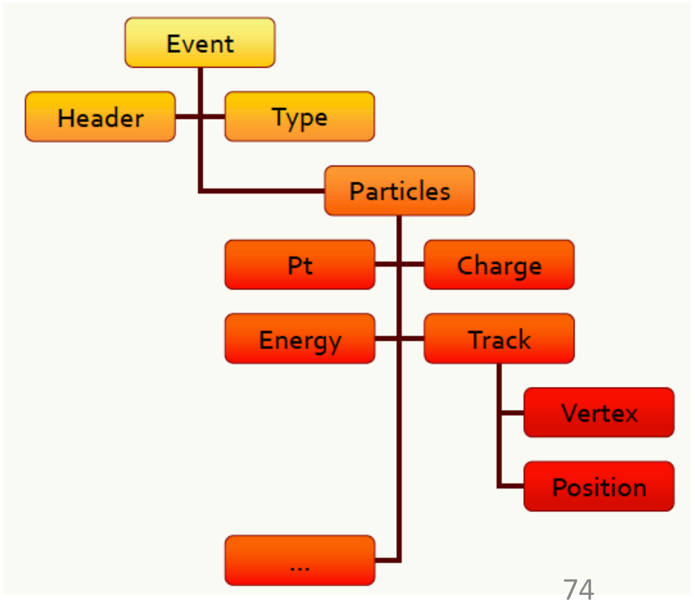
- The TTree is the data structure ROOT provides to store large quantities of same types objects
- Organised in branches, each one holding objects
- Organised in independent events, e.g. collision events
- Efficient disk space usage, optimised I/O runtime



x	y	z
-1.10228	-1.79939	4.452822
1.867178	-0.59662	3.842313
-0.52418	1.868521	3.766139
-0.38061	0.969128	1.084074
0.552454	-0.21231	0.350281
-0.18495	1.187305	1.443902
0.205643	-0.77015	0.635417
1.079222	-0.32739	1.271904
-0.27492	-1.72143	3.038899
2.047779	-0.06268	4.197329
-0.45868	-1.44322	2.293266
0.304731	-0.88464	0.875442
-0.71234	-0.22239	0.556881
-0.27187	1.181767	1.470484
0.886202	-0.65411	1.213209
-2.03555	0.527648	4.421883
-1.45905	-0.464	2.344113
1.230661	-0.00565	1.514559
		3.562347

LEP style flat n-tuples evolved in more efficient trees (fast access, read ahead)





Ntuples

- The `TNtuple` is a simplified version of the `TTree`: store floating point numbers
- As powerful for analysis

Example

Primer macro
write_ntuple_to_file.C

write_ntuple_to_file_cpp

```
TFile ofile("conductivity_experiment.root","RECREATE");
TNtuple cond_data("cond_data”,
                  "Example N-Tuple",
                  "Potential:Current:Temperature:Pressure");
TRandom3 rndm; // We’ll fill random values
float pot,cur,temp,pres;
for (int i=0;i<10000;++i) {
     pot  = rndm.Uniform(0.,10.);     // get voltage
     temp = rndm.Uniform(250.,350.);  // get temperature
     pres = rndm.Uniform(0.5,1.5);    // get pressure
     cur  = pot/(10.+0.05*(temp-300.)-0.2*(pres-1.));// current
     // add some random smearing (measurement errors)
     pot* = rndm.Gaus(1.,0.01); temp+=rndm.Gaus(0.,0.3);
     pres*= rndm.Gaus(1.,0.02); cur*=rndm.Gaus(1.,0.01);
     // write to ntuple
     cond_data.Fill(pot,cur,temp,pres);
}
// Save the ntuple and close the file
cond_data.Write(); ofile.Close();
```

Exercise: Potential of the Tree

- Run the `write_ntuple_to_file.C` macro
- Open the file in the `TBrowser`
- Create plots clicking on the `leaves`

Accessing Complex Trees

- TTreeReader class: tool to access complex trees in a type-safe manner
  - Not only floating point numbers as in TNtuple, but all objects!

```
// Access a TTree called "MyTree" in the file:
TTreeReader reader("MyTree", file);
// Establish links with two of the branches
TTreeReaderValue<float> rvMissingET(reader, "missingET");
TTreeReaderValue<std::vector<Muon>> rvMuons(reader, "muons");
```

Accessing the Data

```
// Loop through all the TTree's entries
// It behaves behaves like an iterator…
while (reader.Next()) {
    float missingET = *rvMissingET;
    …
    for (auto&& mu: rvMuons) { hist->Fill(pT); }
}
```

TTreeReader_Example_cpp

PyROOT

- ROOT offers the possibility to interface to Python via a set of bindings called PyROOT
- Mix the power of C++ (compiled libraries) and flexibility of Python
- Killer application: JIT of C++ code from within Python
  - Real mix of the two languages

See Primer's section 8 for more details

Entry point to use ROOT from within Python:

```
import ROOT
```

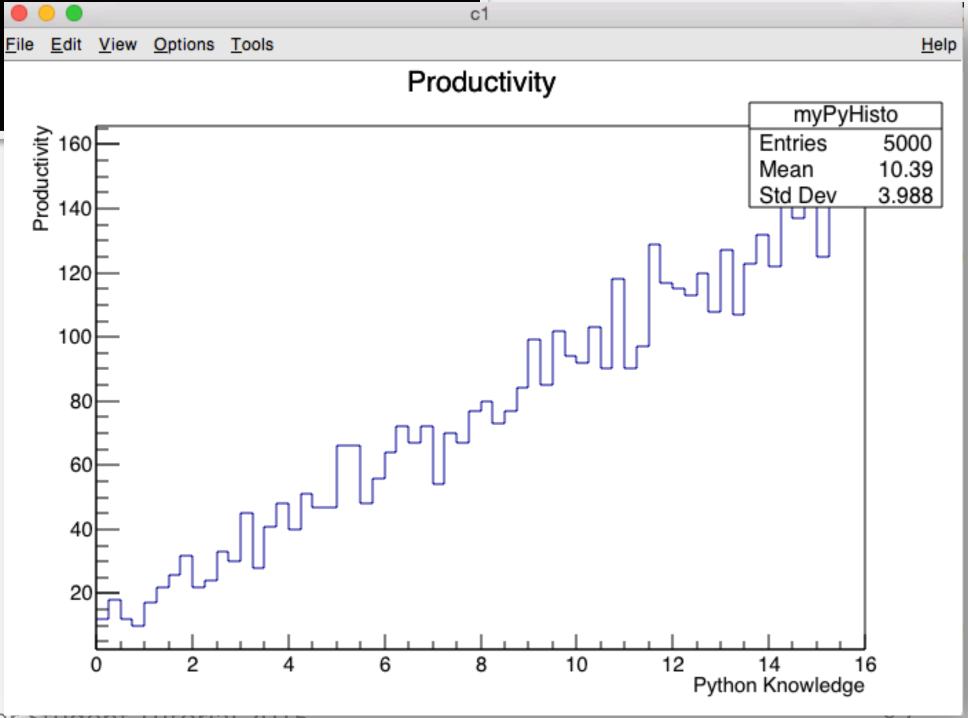
All classes you now know can be accessed like ROOT.TH1F, ROOT.TGraph, …

Extempore Exercise

- Open the Python interpreter (type python)
- Import the ROOT module
- Create an histogram with 64 bins and a x axis ranging from 0 to 16
- Fill it with random numbers distributed according to a linear function ("pol0")
- Change its line width with a thicker one
- Draw it!

Extempore Exercise

```
~> python
>>> import ROOT
>>> h = ROOT.TH1F("myPyHisto","Productivity;Python Knowledge;Productivity",
64,0,16)
>>> h.FillRandom("pol1")
>>> h.Draw()
```



```
myPyHisto
Entries      5000
Mean        10.39
Std Dev     3.988
```

FillHistogram_Example_py

TTreeAccess_Example_py

Review of the objectives

Objectives:

- Become familiar with the ROOT toolkit
- Be able to use the C++ prompt
- Plot data
- Fit data
- Perform basic I/O operations