ROOT

Data Analysis Framework

Summer Students Course 2016

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This Course

This is an introductory ROOT Workshop.

Objectives:

- Become familiar with the ROOT toolkit
- Be able to use the C++ prompt
- Plot data
- Fit data
- Perform basic I/O operations
- Learn about SWAN and Jupyter notebooks

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): https://root.cern.ch/guides/primer
- Code examples can be visualised with the Jupyter Notebooks available at:
  http://swan.web.cern.ch/content/root-primer

- Signaled with name and the sign:  followed by the notebook's name

Two release series of ROOT are available: ROOT5 and ROOT6
This lecture refers to ROOT6, version 6.06

How Can I Run ROOT?

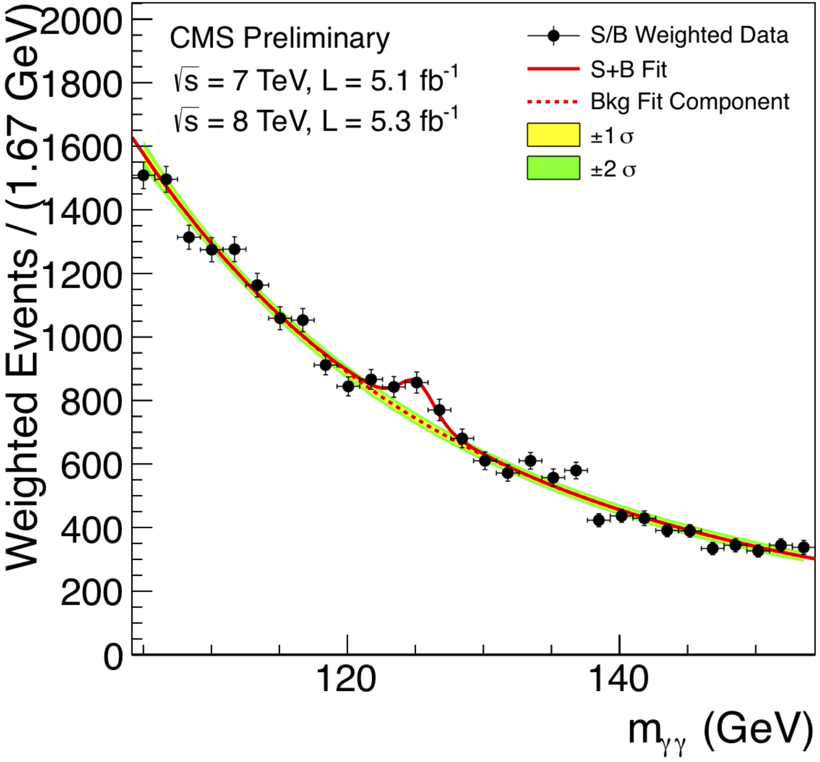
You can choose between three options:

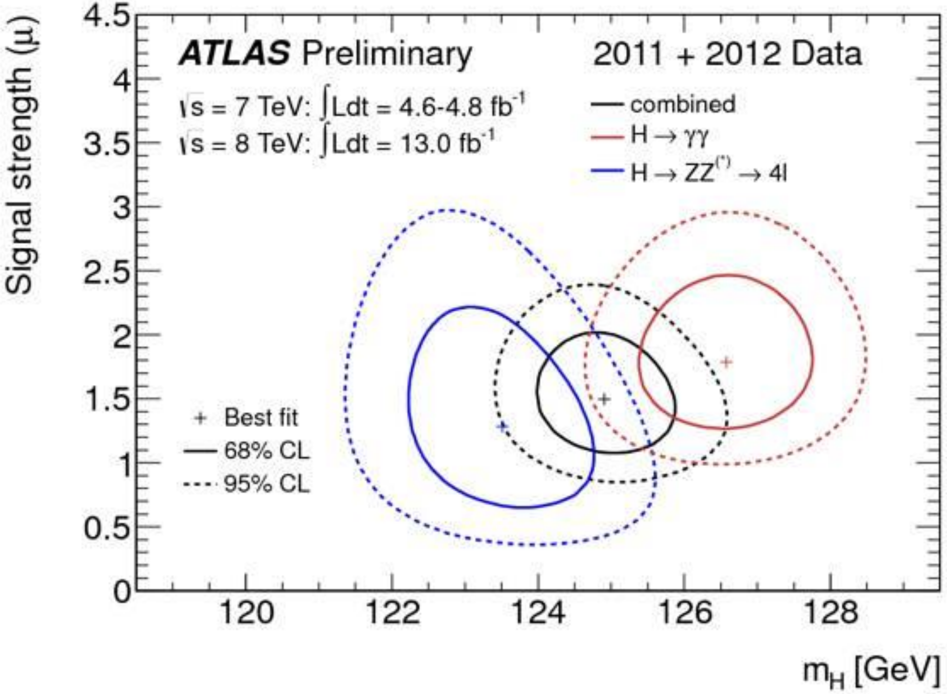
1. Local ROOT installation
   - https://root.cern.ch/downloading-root
2. ROOT Virtual Machine
   - https://github.com/root-mirror/training
3. SWAN
   - No installation needed: only a web browser
   - Preparation: log into CERNBox at https://cernbox.cern.ch
   - Access SWAN service at https://swan001.cern.ch

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 is 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

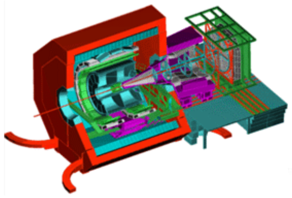
ROOT in a Nutshell

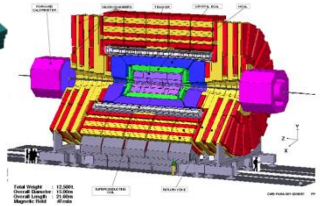
ROOT can be seen as a collection of building blocks for various activities, like:

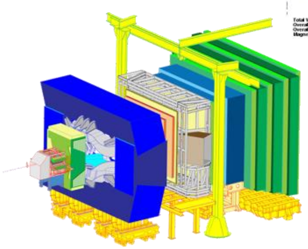
- Data analysis: histograms, graphs, trees
- I/O: row-wise, column-wise storage of **any** C++ object
- Statistical tools (RooFit/RooStats): rich modeling and statistical inference
- Math: non trivial functions (e.g. Erf, Bessel), optimised math functions (VDT)
- C++ interpretation: fully C++11 compliant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

ROOT Application Domains

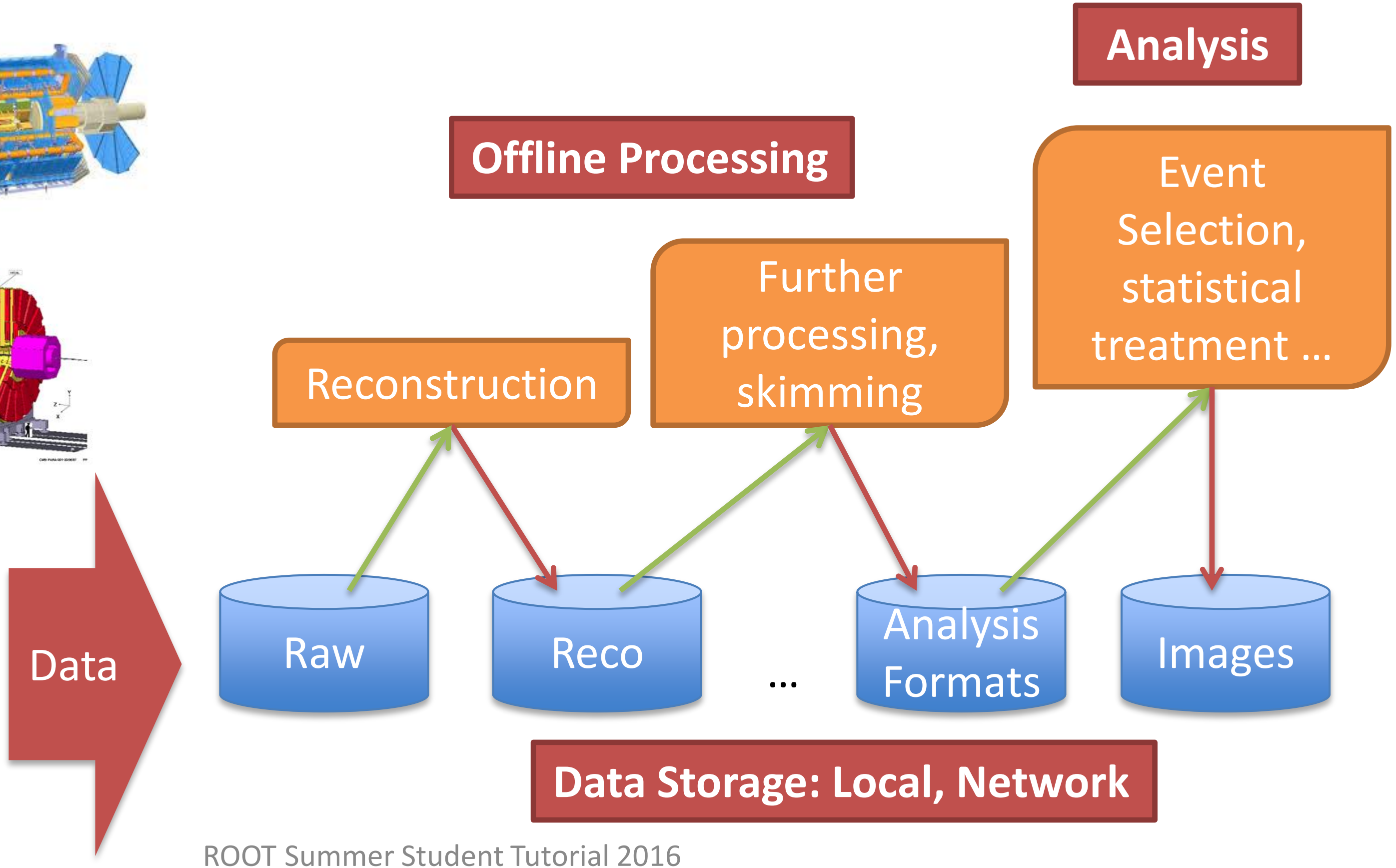
A selection of the experiments adopting ROOT





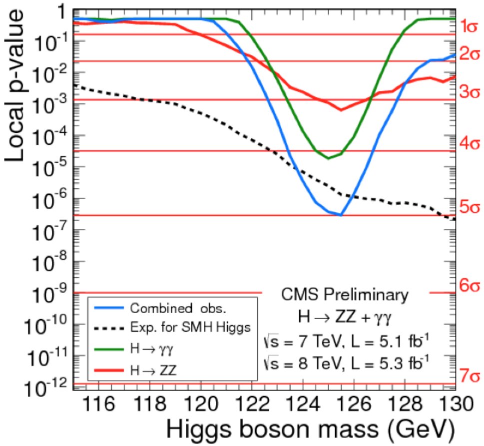


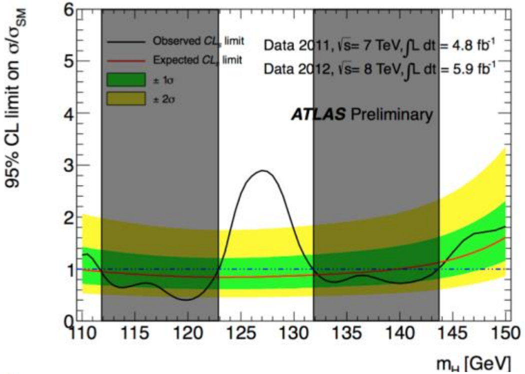
Event Filtering

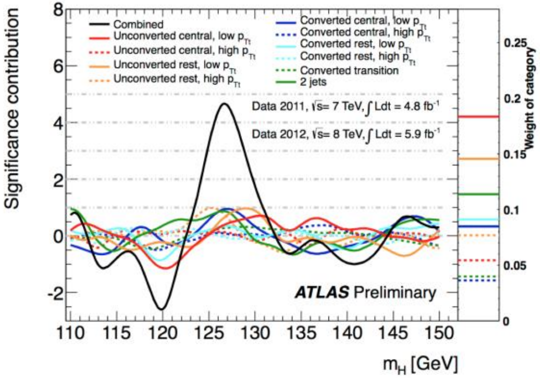


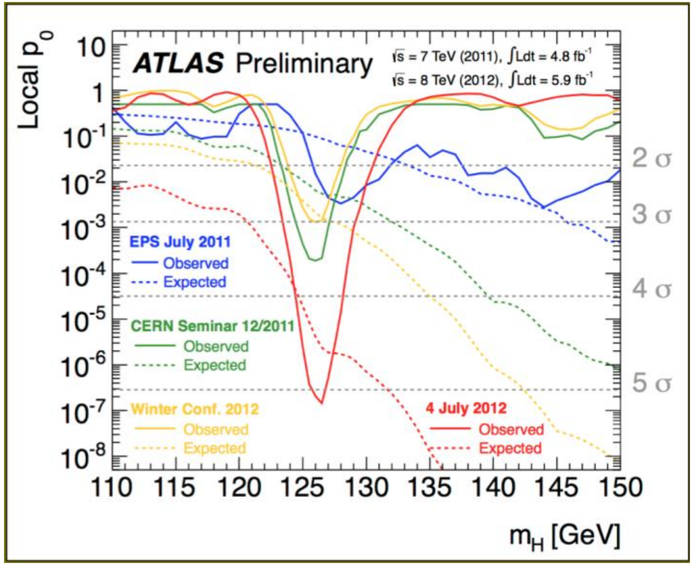
Higgs boson discovery

On July 4th 2012, the plots presented by the ATLAS and CMS collaborations where all produced with ROOT !





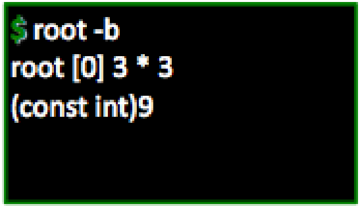




Interpreter

ROOT has a built-in 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.



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

- This is impossible with C++ alone.
- Used the LHC detectors to write several petabytes per year.

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

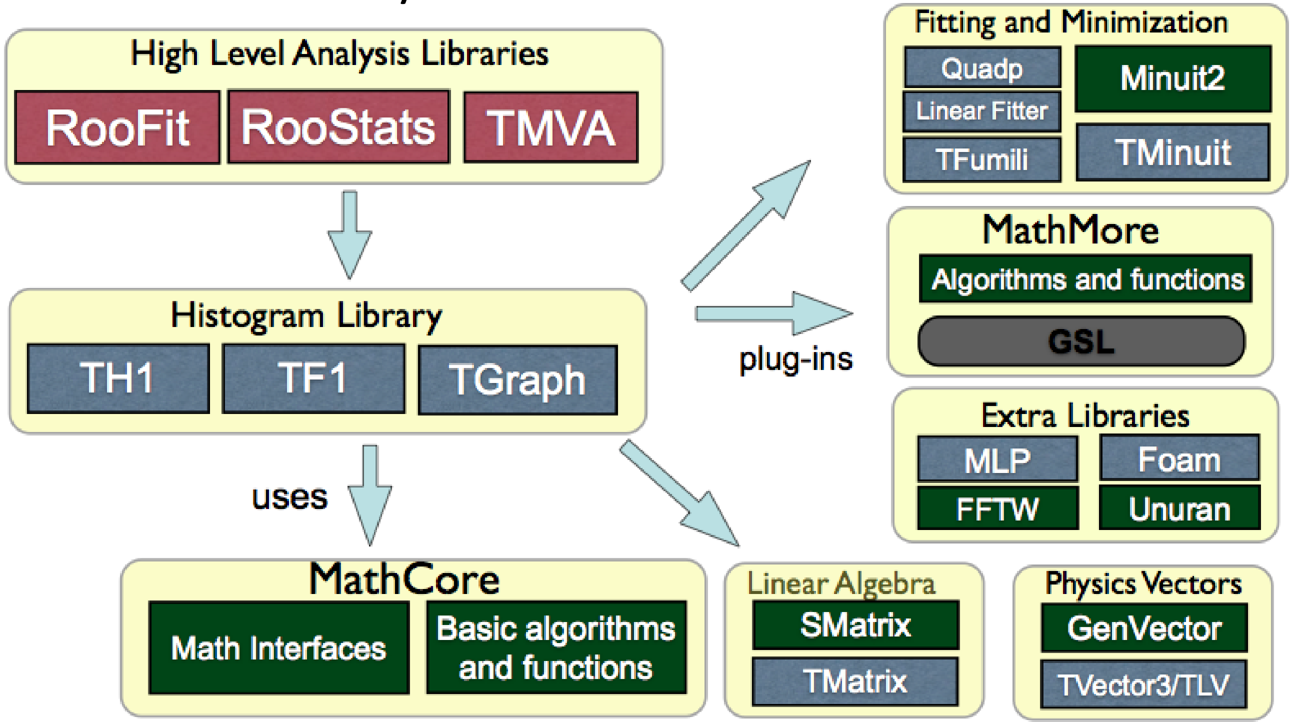
- Raw and column-wise streaming

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

Cornerstone for storage of experimental data

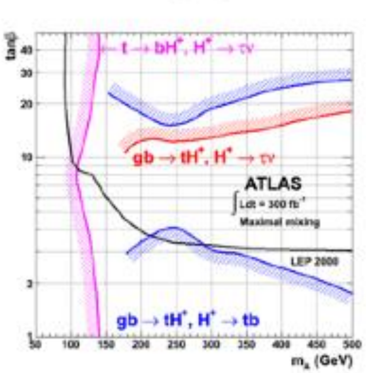
ROOT Math/Stats Libraries

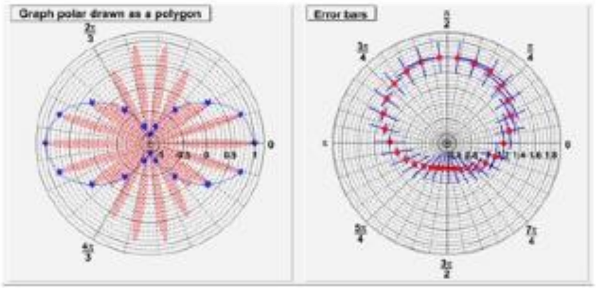
ROOT provides a reach set of mathematical libraries and tools needed for sophisticated statistical data analysis

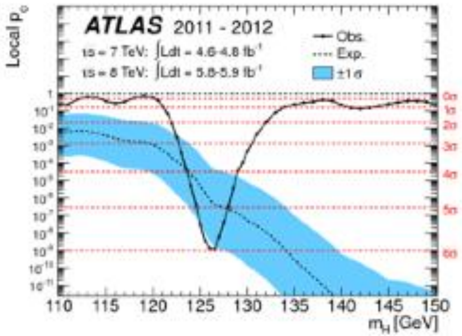


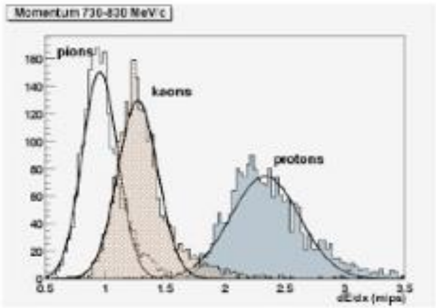
Graphics In ROOT

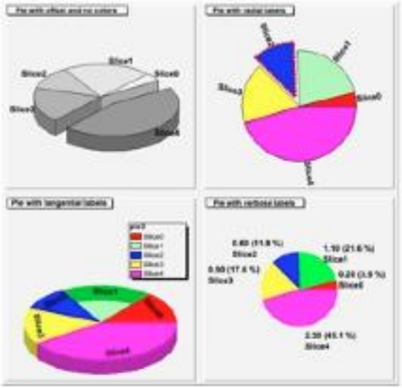
Many formats for data analysis, and not only, plots

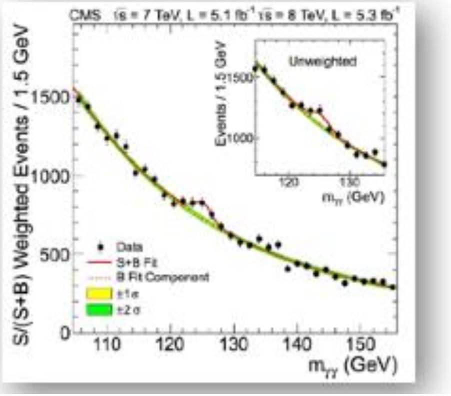










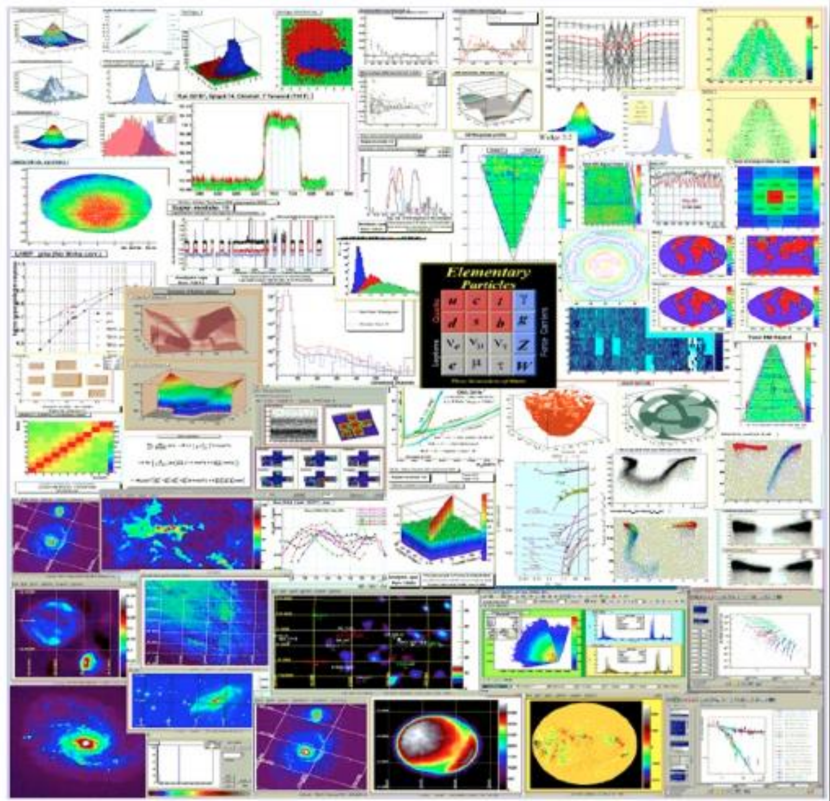


2D Graphics

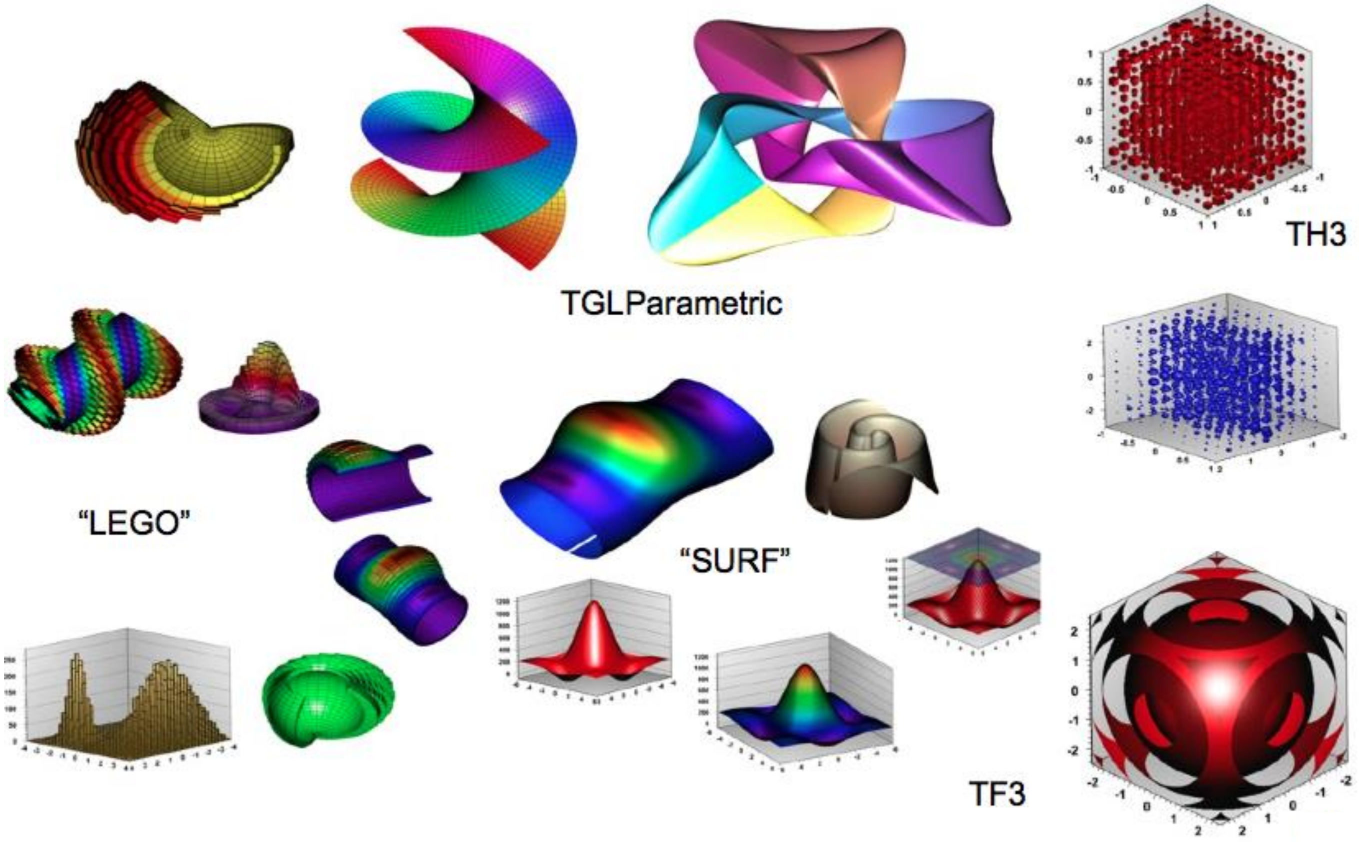
New functionalities added at every new release

Always requests for new style of plots

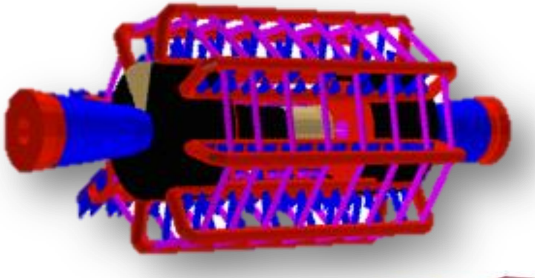
Can save graphics in many formats: *ps, pdf, svg, jpeg, LaTex, png, c, root …*



3D Graphics



Other ROOT Features

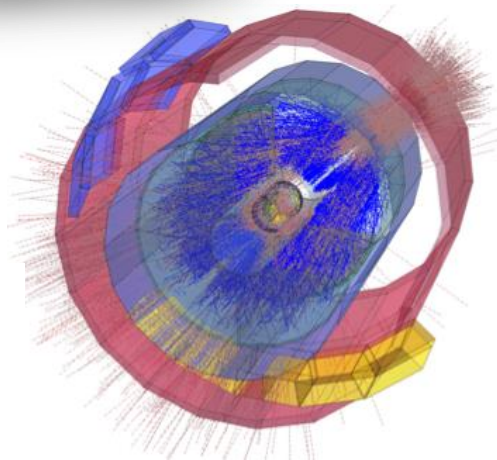


Geometry Toolkit

- Represent geometries as complex as LHC detectors

Event Display (EVE)

- Visualise particles collisions within detectors

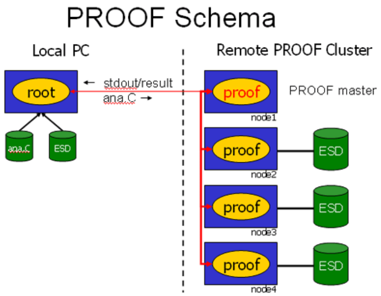


Multiproc

- Parallel shared-memory Map-Reduce

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



The SWAN Service

Data analysis with ROOT "as a service"

Interface: Jupyter Notebooks

Goals:

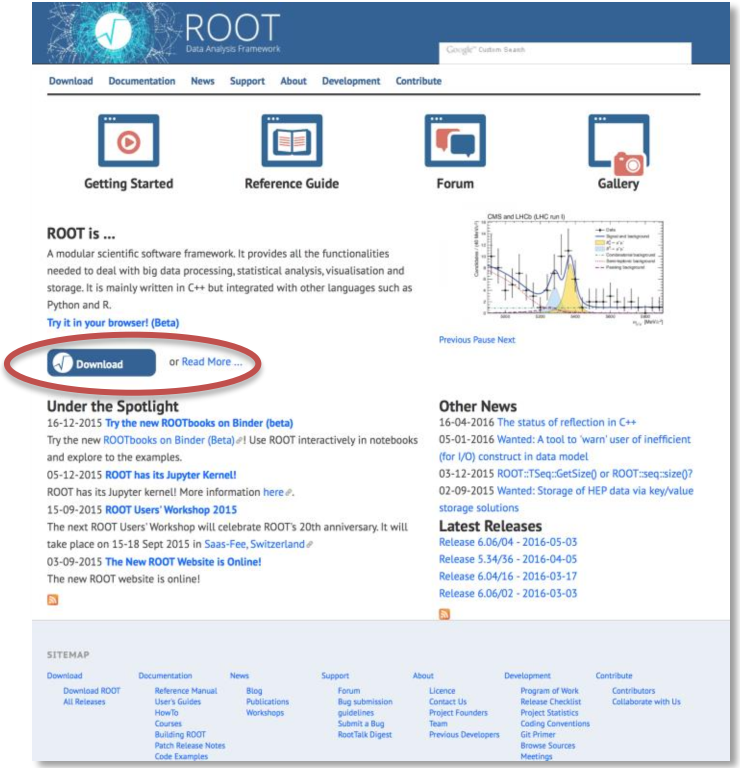
- Use ROOT only with a web browser
  - Platform independent ROOT-based data analysis
  - Calculations, input and results "in the Cloud"
- Allow easy sharing of scientific results: plots, data, code
  - Through your CERNBox
- Simplify teaching of data processing and programming

http://swan001.cern.ch

root.cern

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!

A Few Q/A

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

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

! **2.** You join a huge users' community, and a very supportive team of core developers

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

! Performance. Support for languages like Python

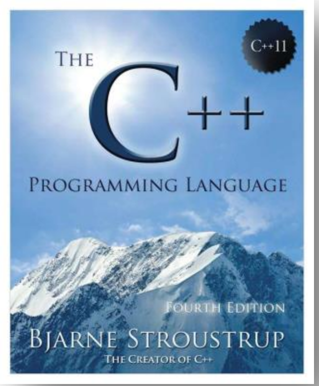
? *Why prompt and libraries instead of a GUI ?*

! 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 get the best performance from the hardware
- Allows object orientation
- Generic programming: Templates
- Explicit memory management (pointers)



Main language of HEP (together with Python)

- In the 90s nearly all legacy FORTRAN HEP code has been migrated 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();


MyClass *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++, without the need of a compiler, like Python, Ruby, Haskell …
- Allows reflection (inspect at runtime layout of classes)
- Is started 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 !

Try it!

```
root [0] 1+1
(int)2
root [1] 2*(4+2)/12.
(double) 1.00000
root [2] sqrt(3.)
(double) 1.73205
root [3] 1 > 2
(bool) false
```

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) 3.14159
root [5] TMath::Erf(.2)
(Double_t) 0.222703
```

ROOT As a Calculator++

Here we make a step forward.
We Declare **variables** and used a ***for*** control structure.

Tab-completion is available. Try it.

```
root [6] double x=.5
(double) 5.00000
root [7] int N=30
(int) 30
root [8] double gs=0
(double) 0.00000
```

```
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:

- To quit root use .q
- To issue a shell command use .!<OS_command>
- To load a macro use .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 [1] 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 [1] 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(-
v*v*.5) – TMath::Gaus(v) << 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();
```

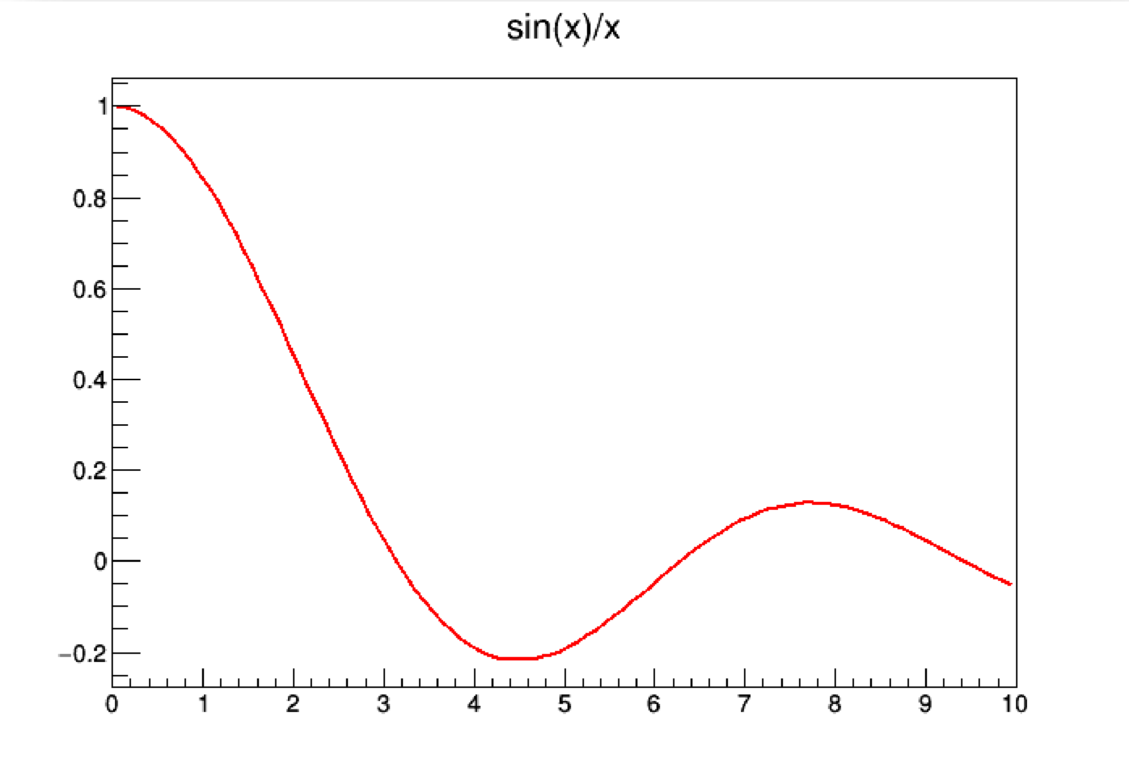
ROOT As a Function Plotter

The class TF1):

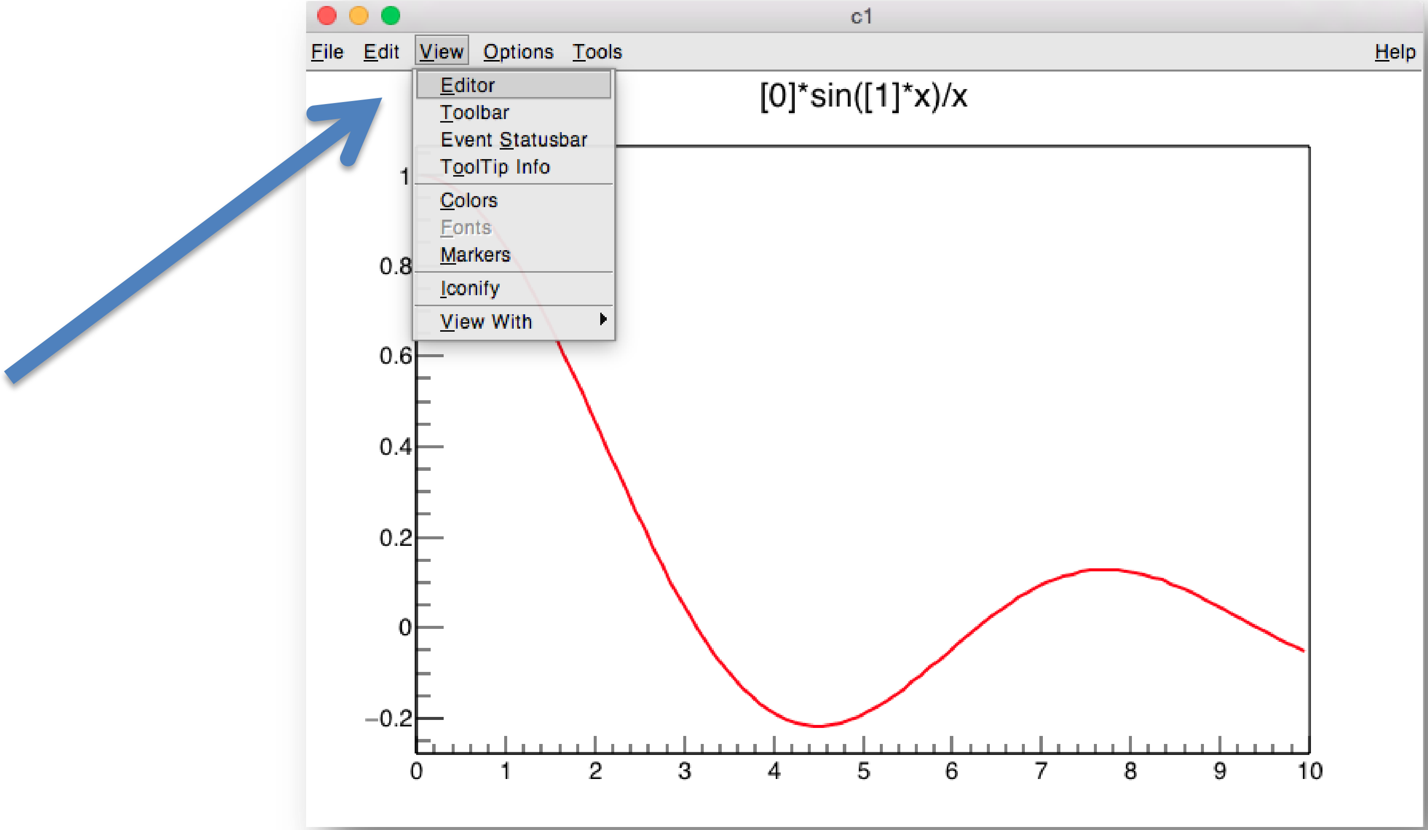
```
root [0] TF1                                    min, max
root [1] f1.D
```

An extended v   ion
with paramete

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



Exercise: Interaction With The Plot



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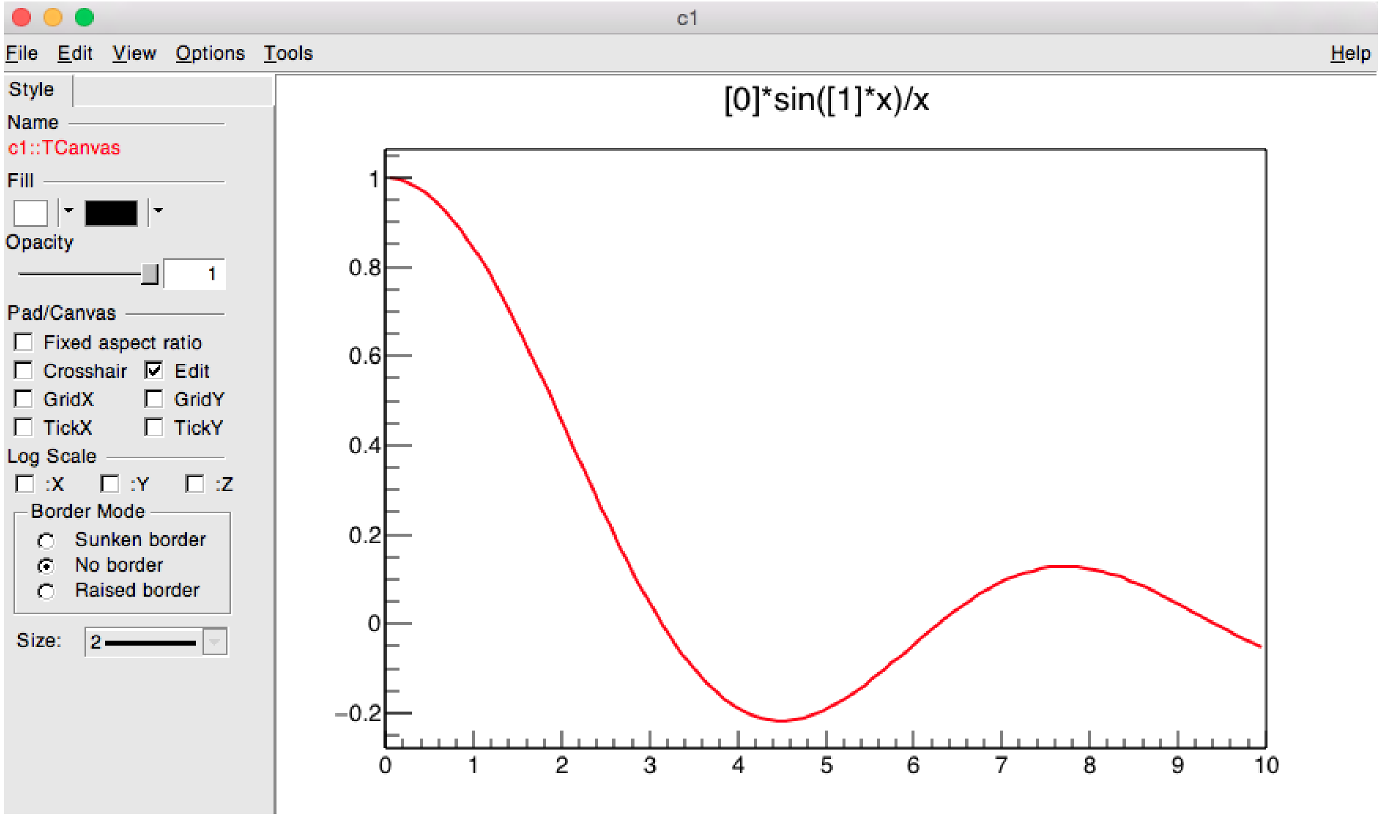
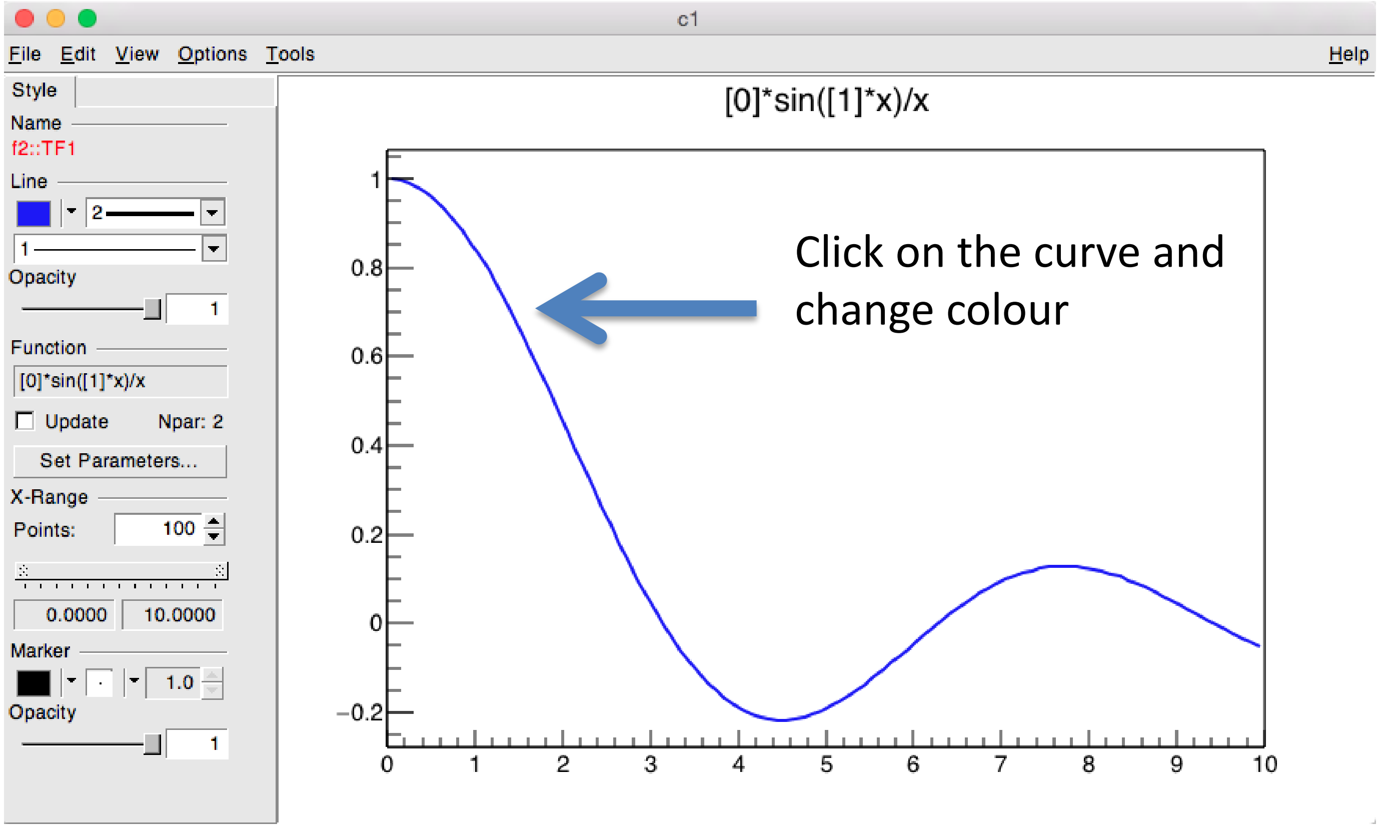
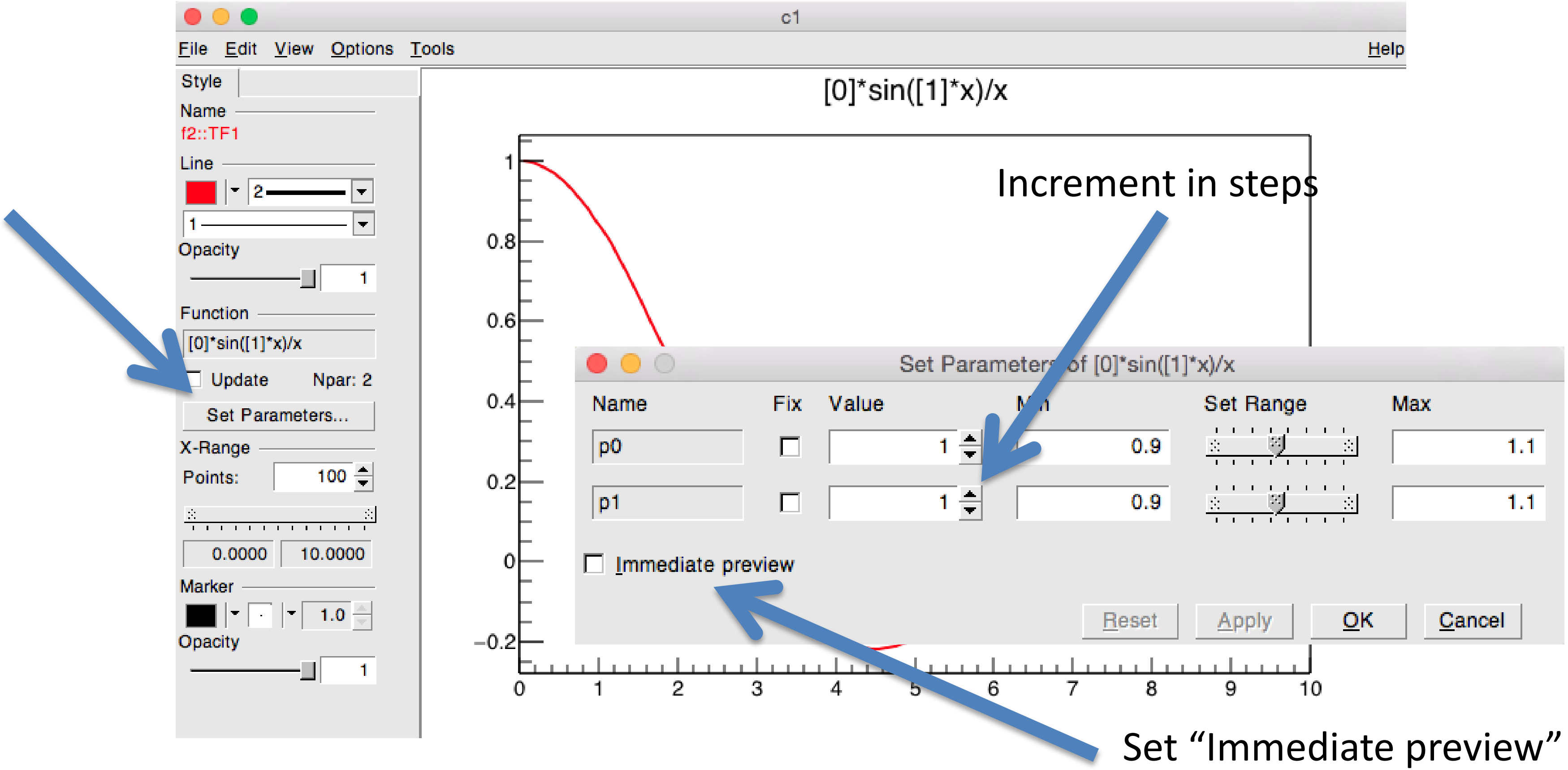


Exercise: Interaction With The Plot



Click on the curve and change colour

Exercise: Interaction With The Plot



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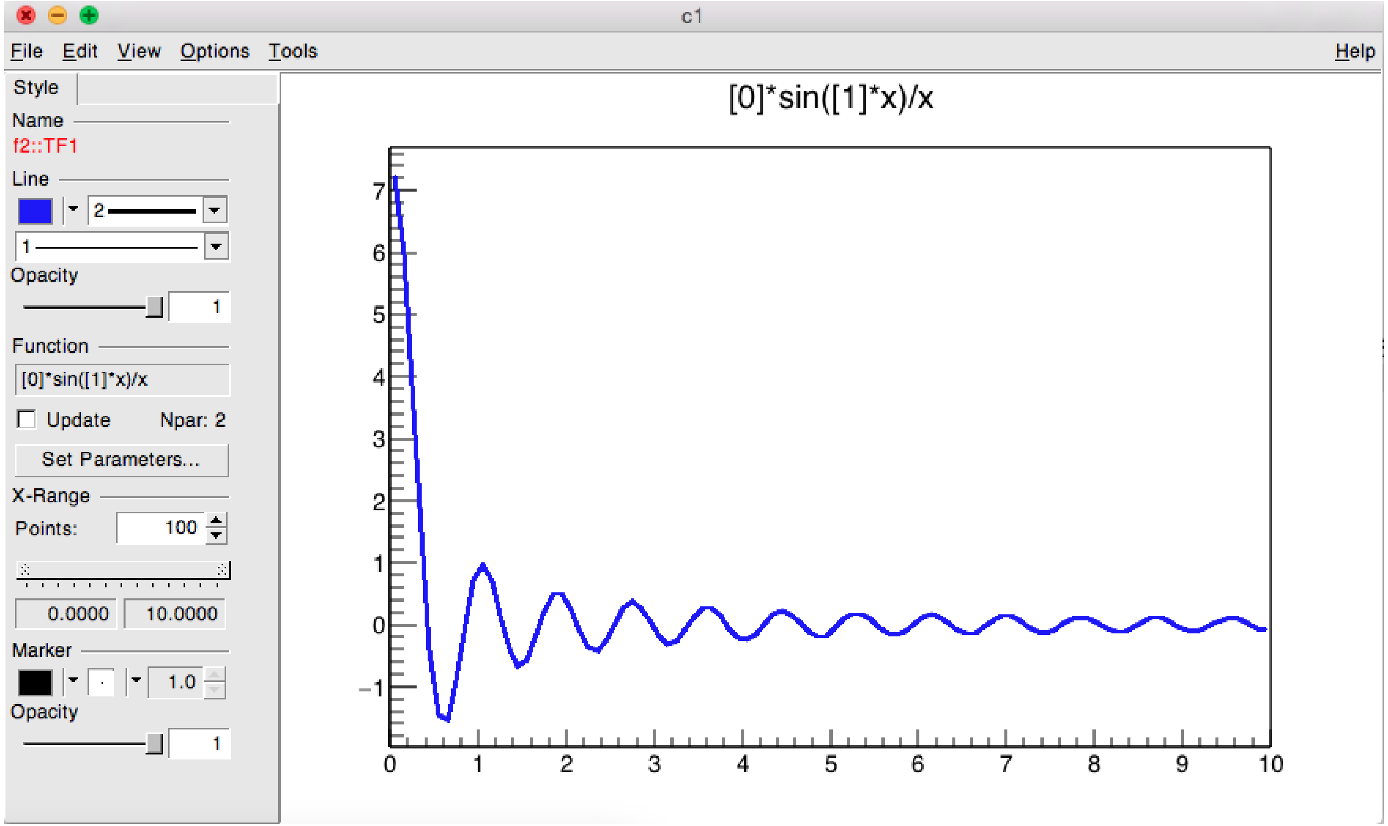

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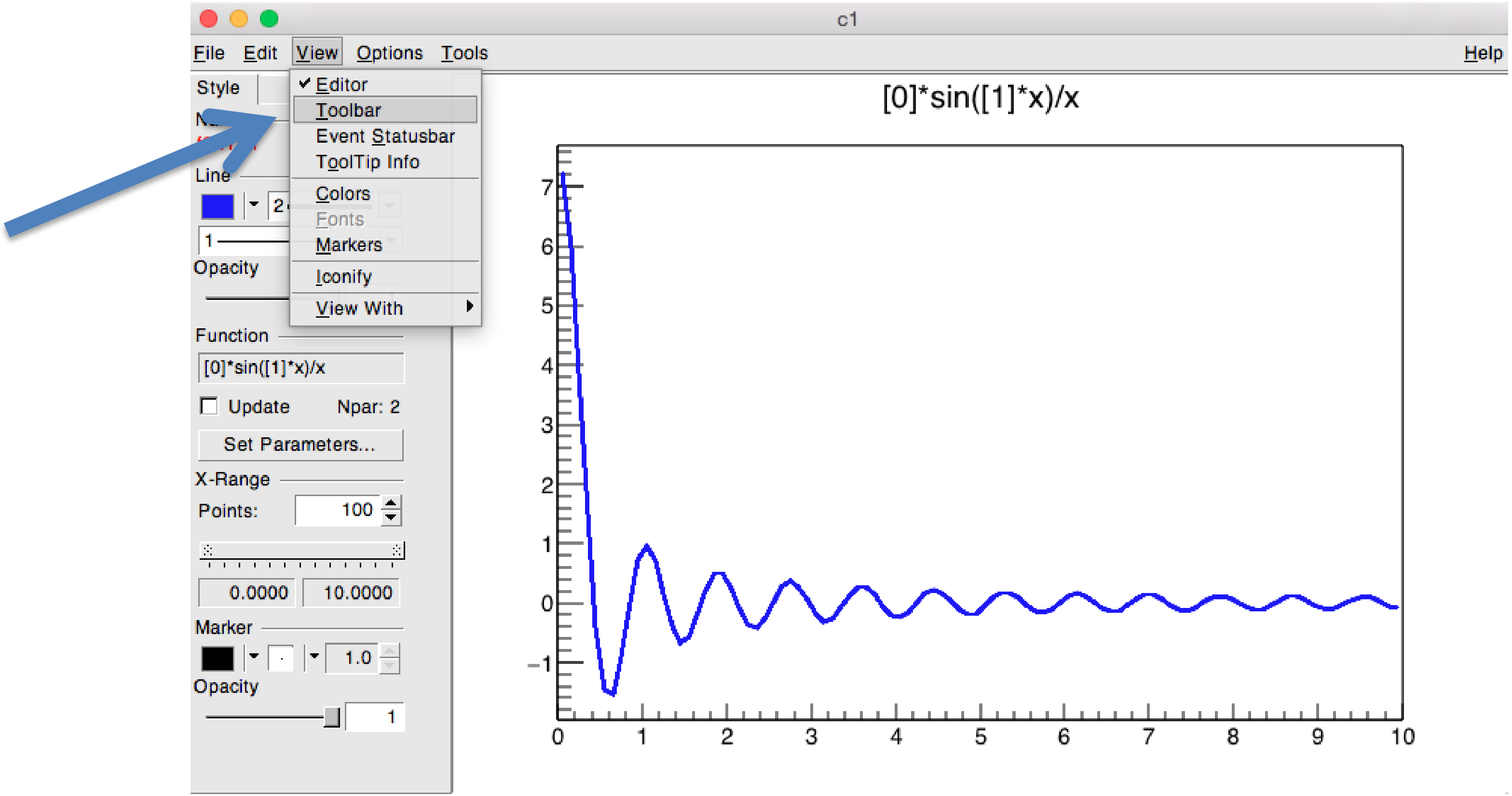

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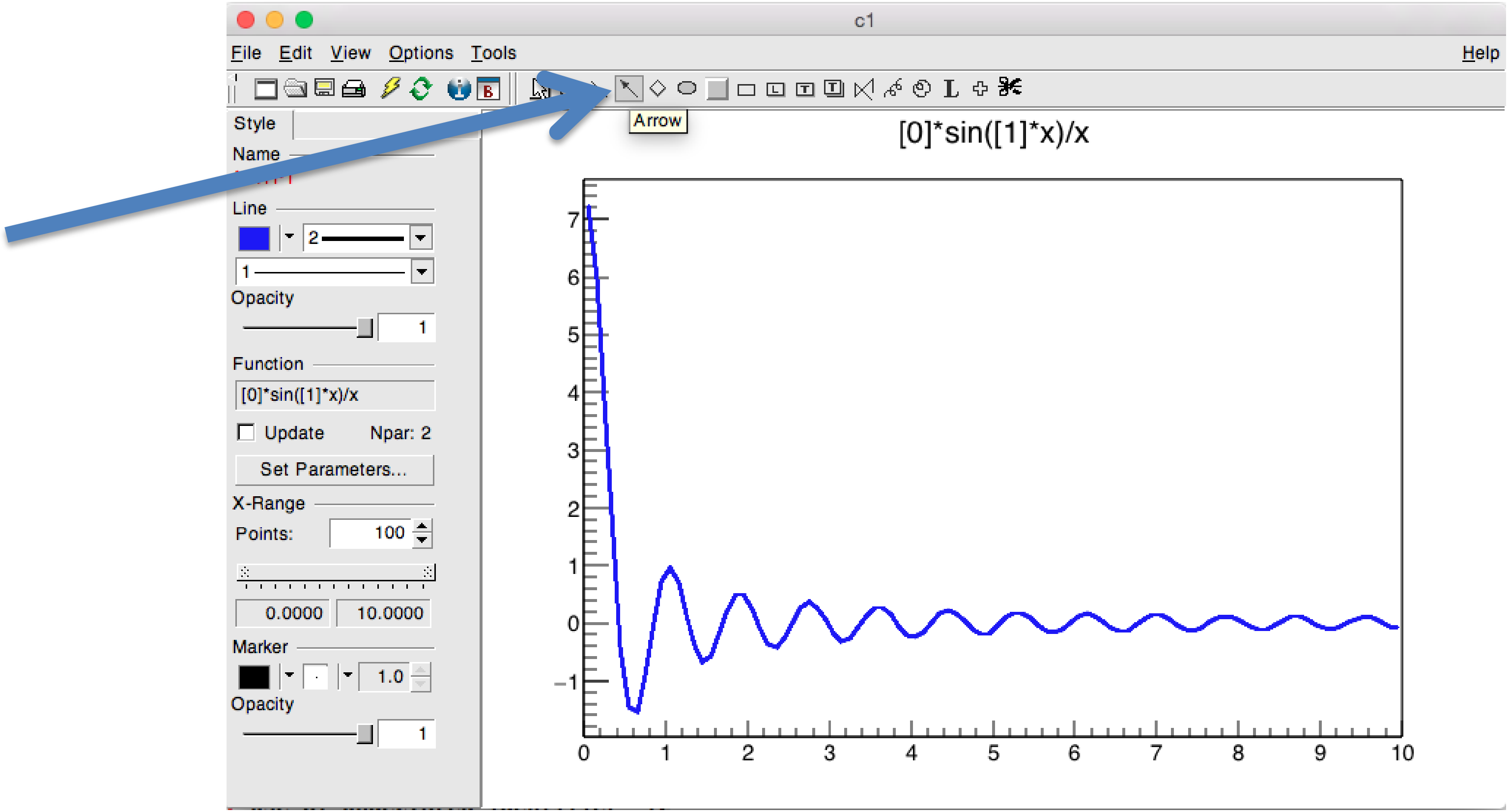

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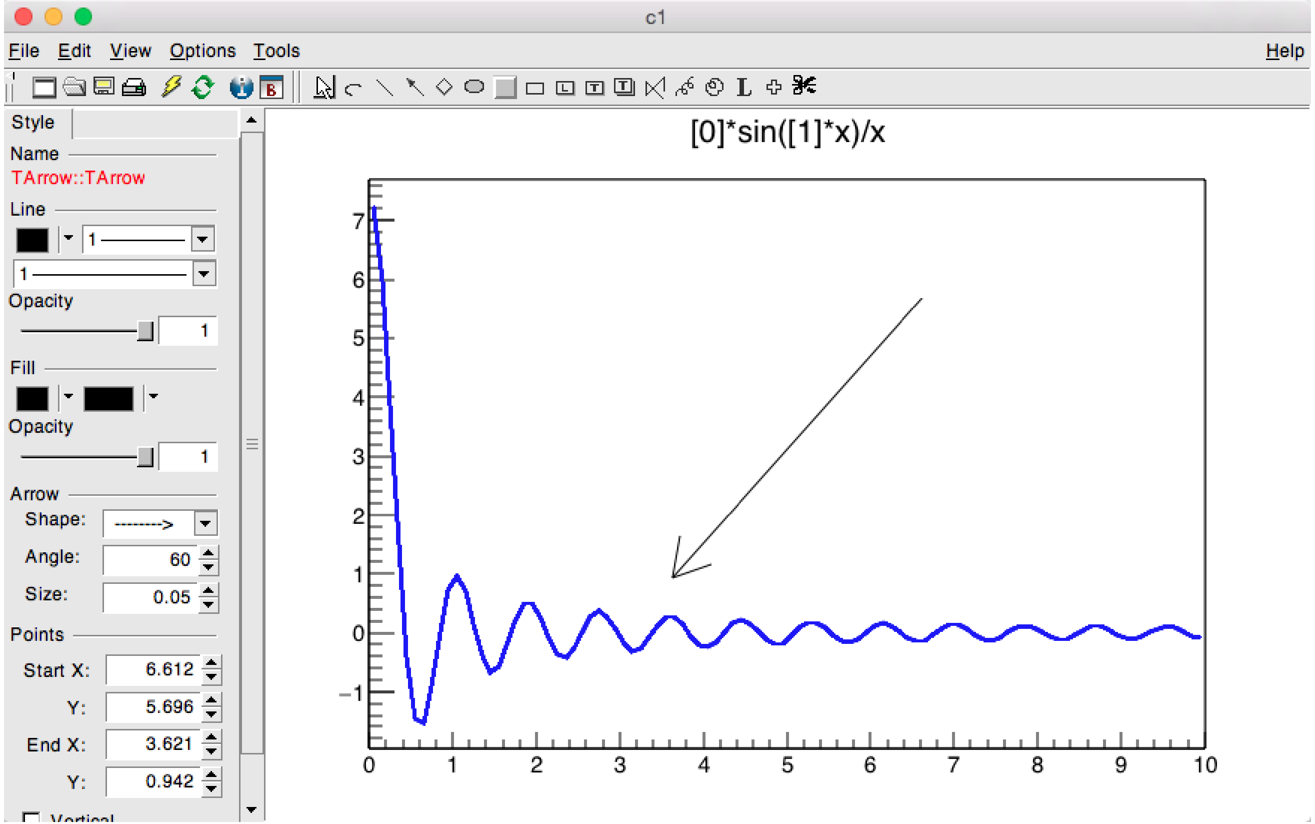
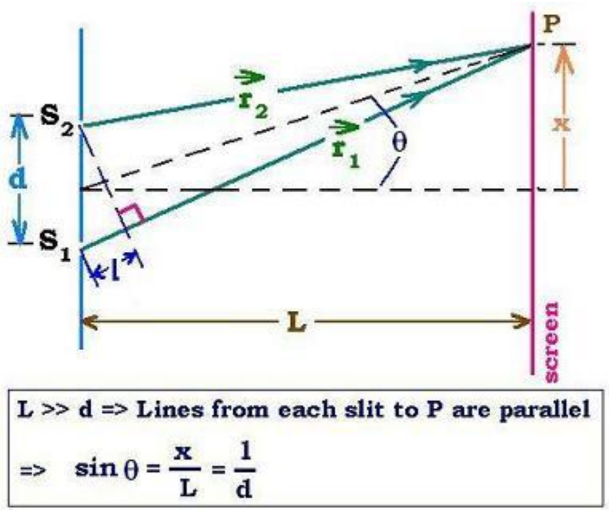
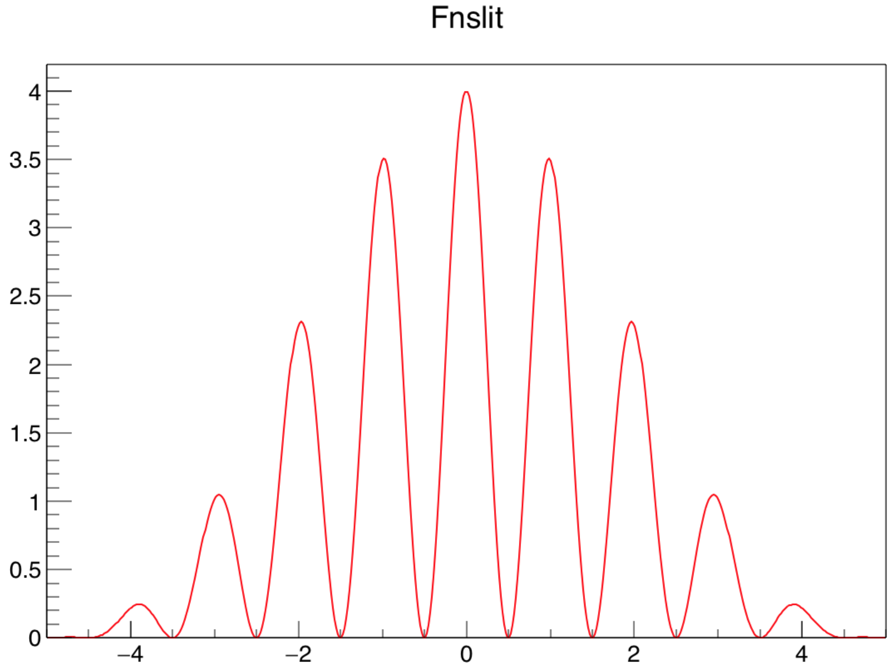


ROOT As a Function Plotter

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

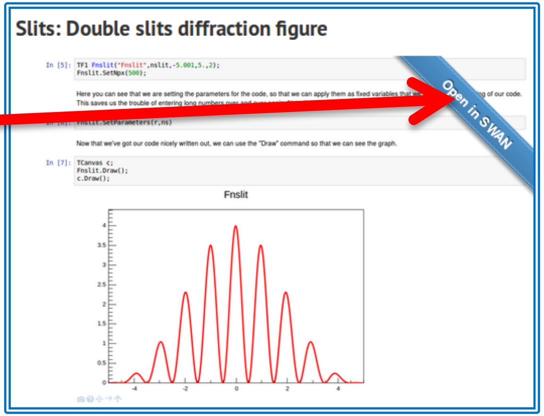




Now Try It in SWAN!

http://swan.web.cern.ch/content/root-primer

Click to open the Slits notebook in SWAN



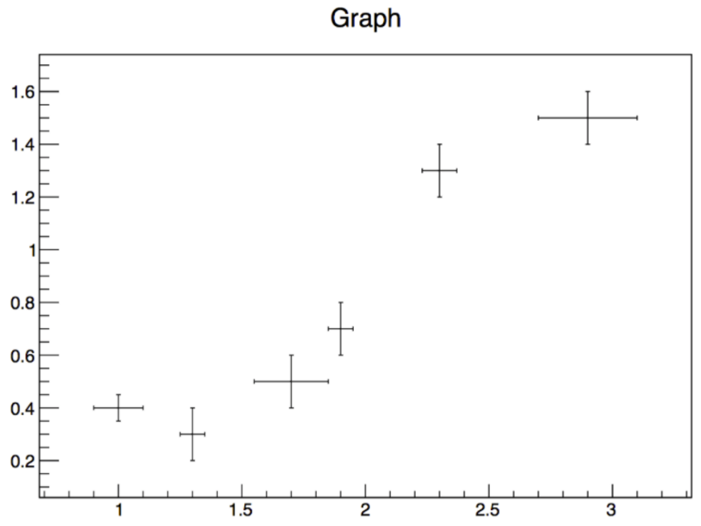
Slits_cpp

Plotting Measurements

The class TGraphErrors allows to display measurements, 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

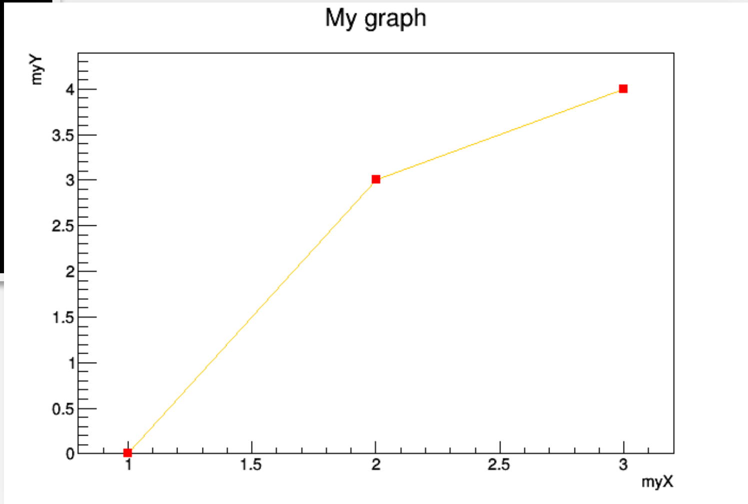


Exercise: TGraph

- 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 an orange line between points

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")
```

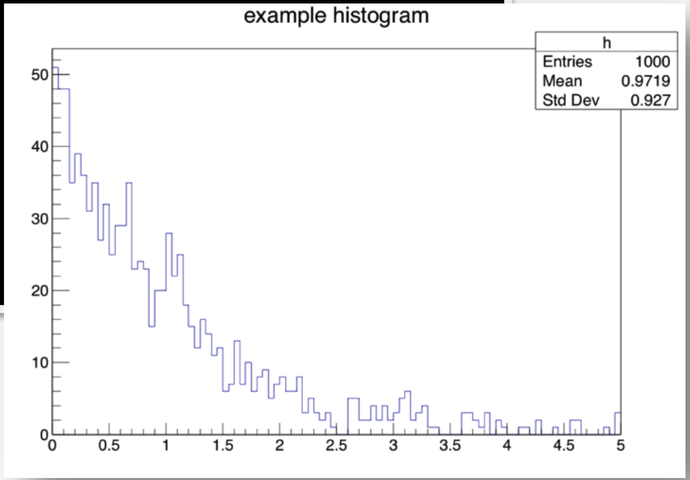


Histograms

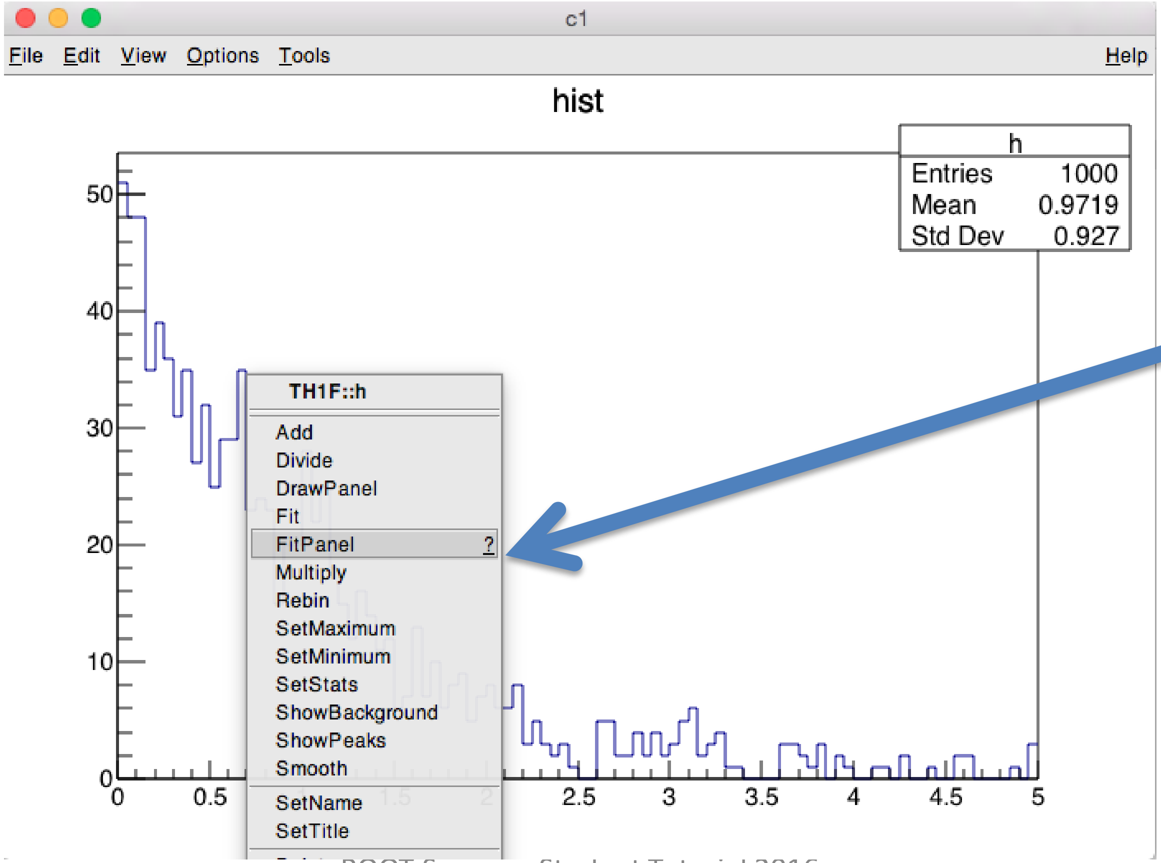
- The TH* classes represent histograms
- TH1* are monodimensional, TH2* are bidimensional …
- The final letter describes the type stored in each bin:

  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()
```

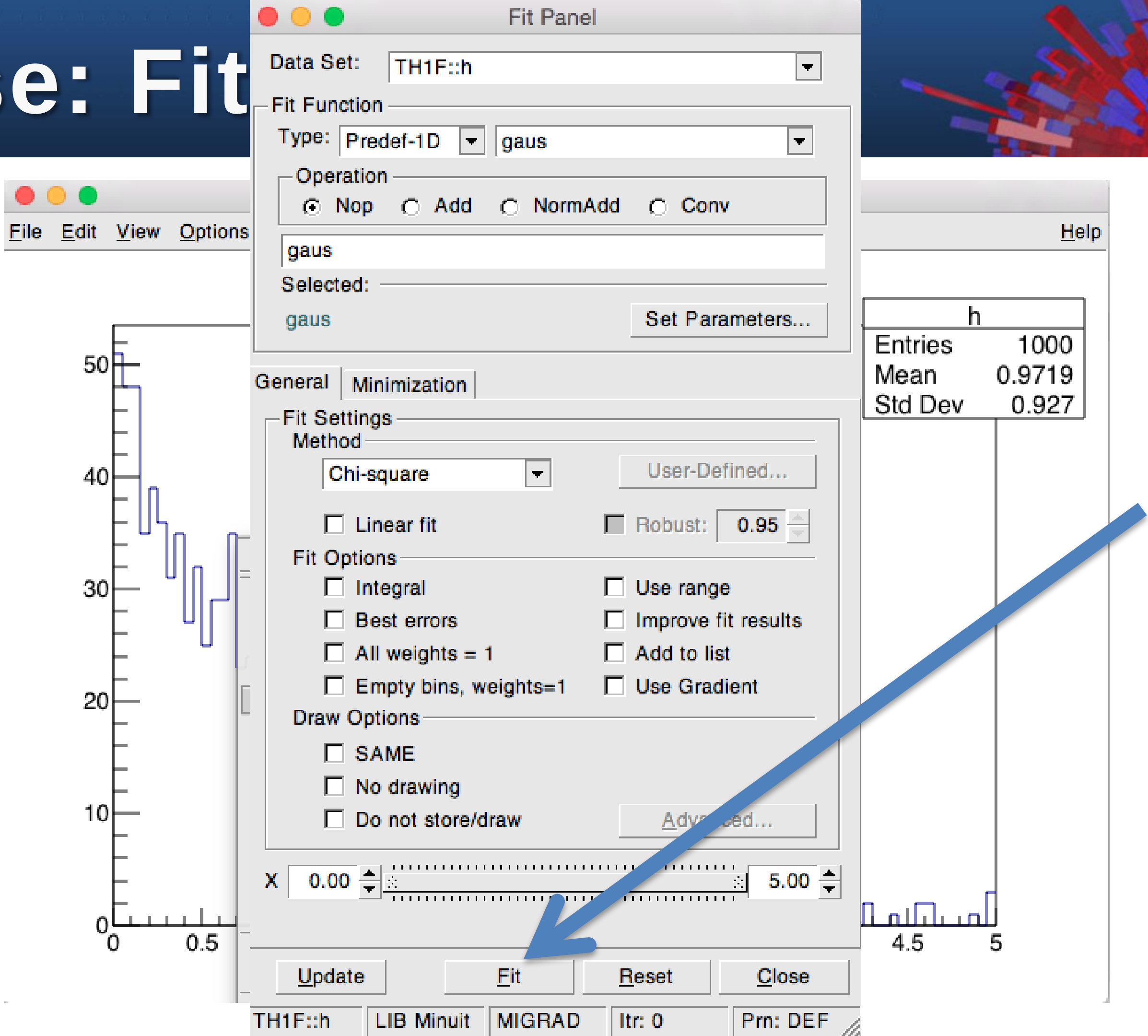


Exercise: Fitpanel



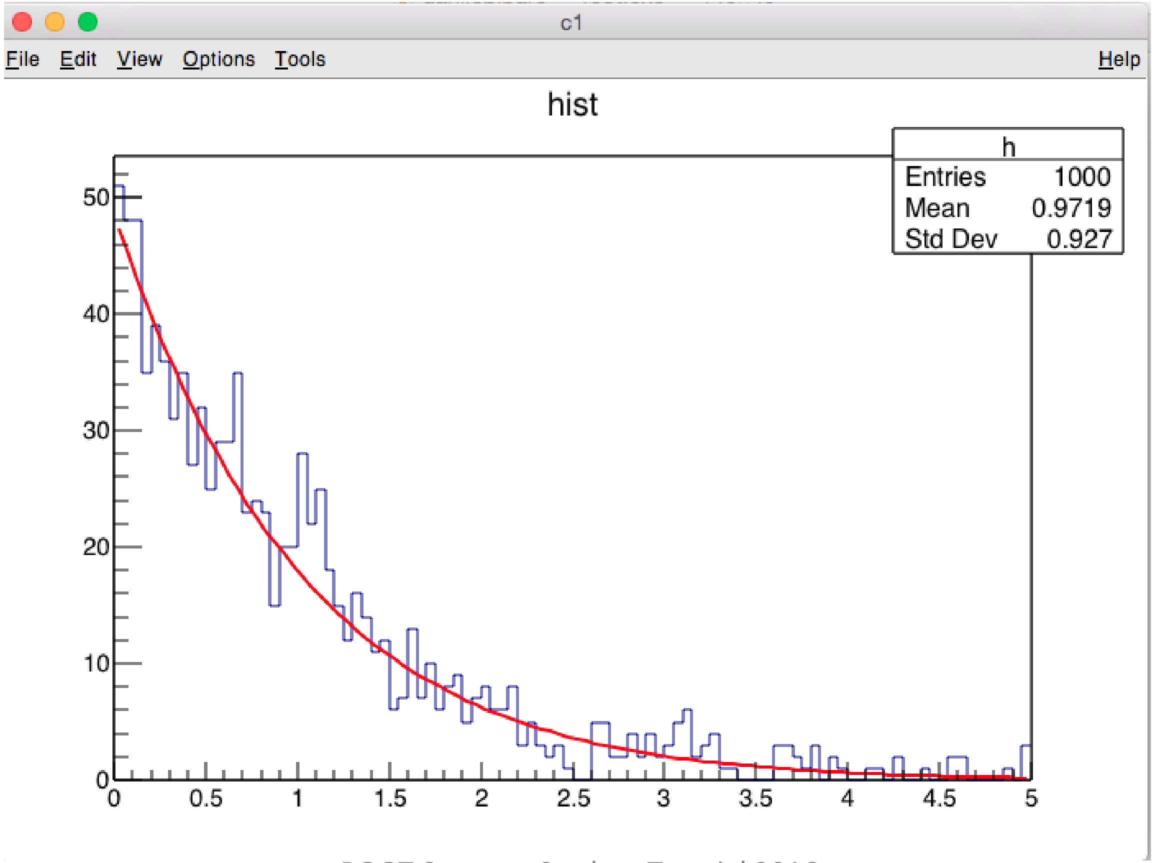
Click on the histogram “line”

Exercise: Fit



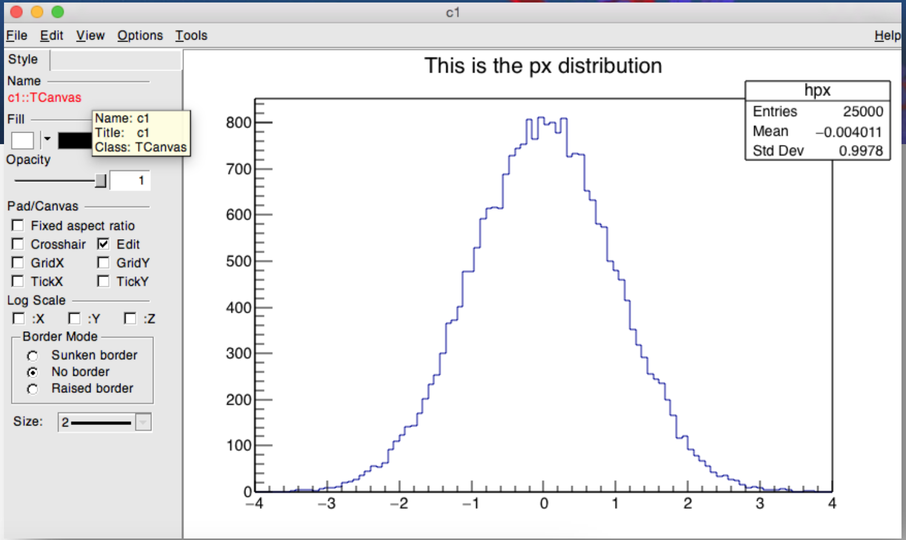
Fit!

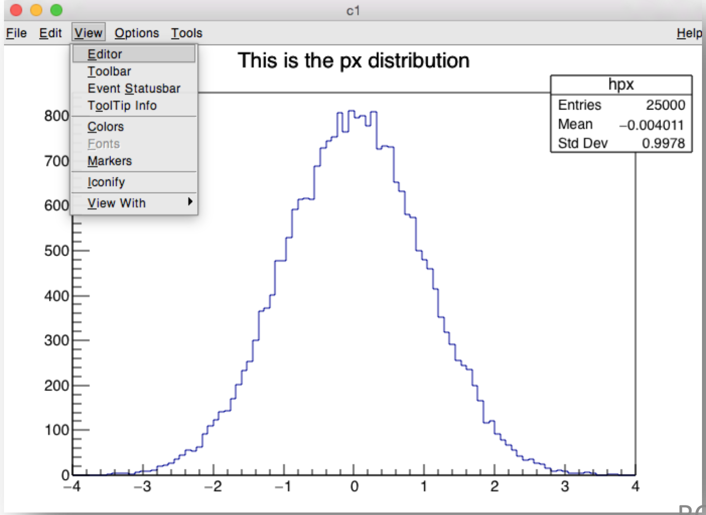
Exercise: Fitpanel

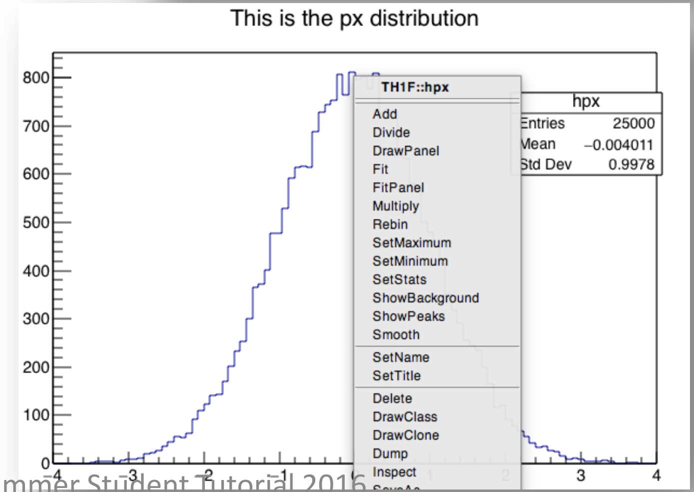


Interactive ROOT

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







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

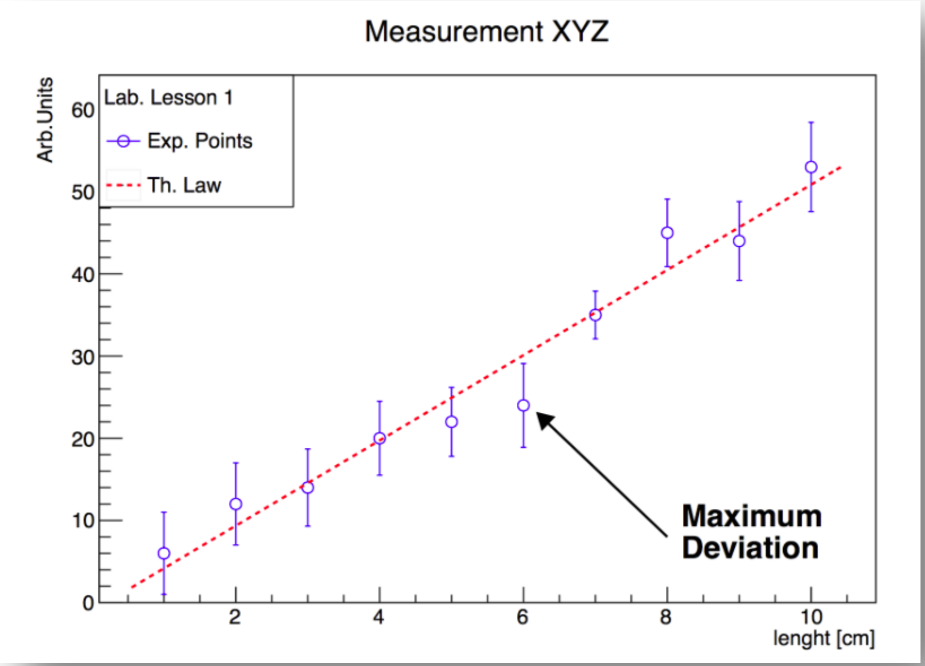
The example in section 3.2 of the ROOT primer, is a typical task in data analysis, a macro that constructs a graph with errors, fits a (linear) model to it and saves it as an image.

Let's inspect it together.

A More Complex Example

And Run it!

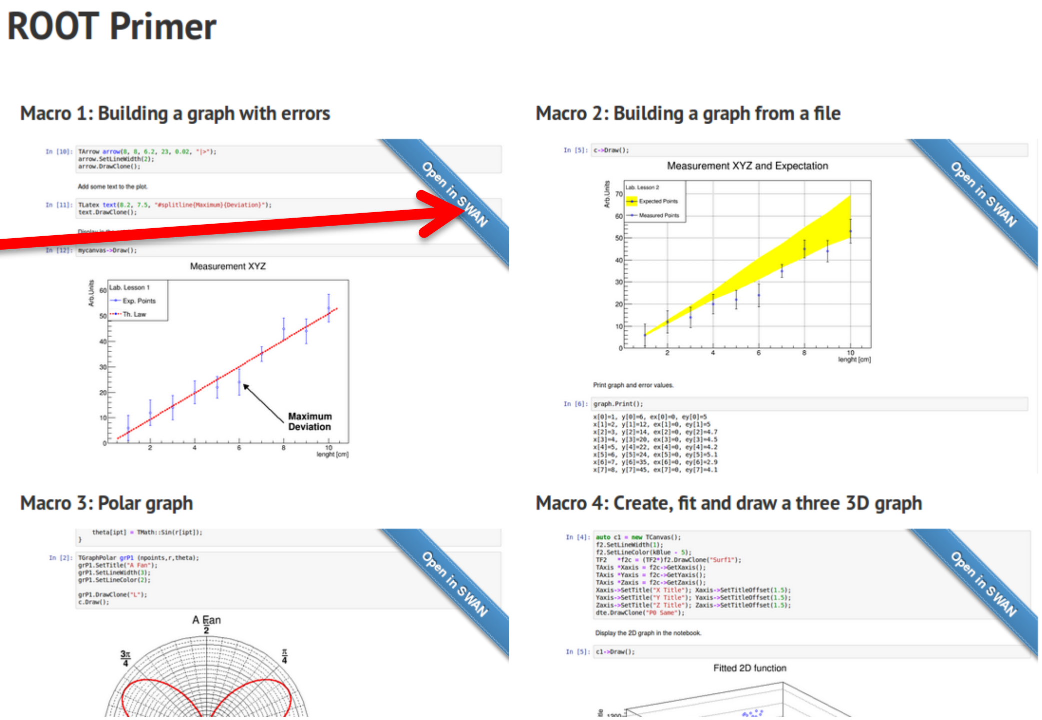
```
> root macro1.C
```



Macros available in SWAN

http://swan.web.cern.ch/content/root-primer

Click to open the Macro 1 notebook in SWAN



Macro1_cpp

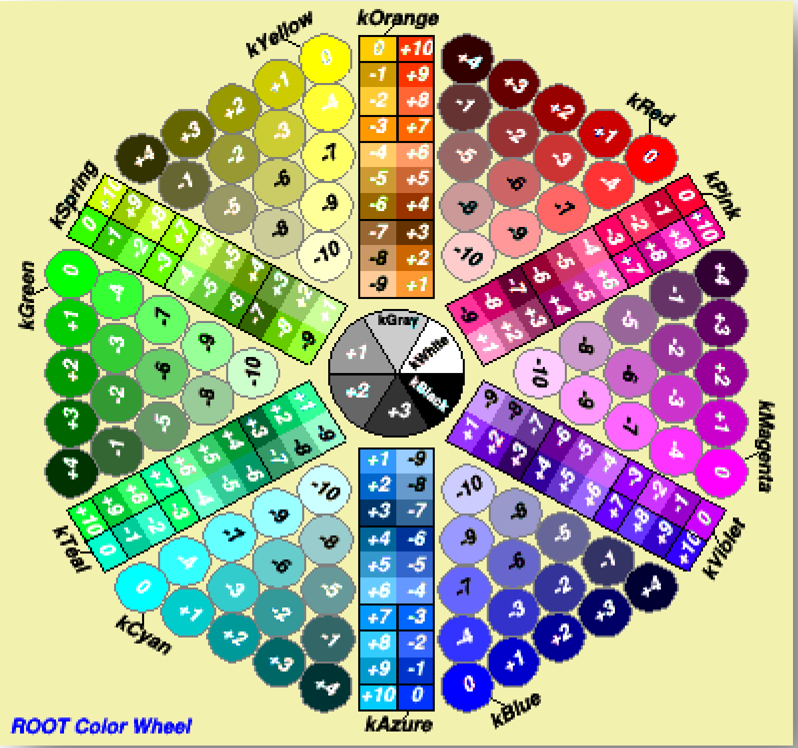
Summary of Visual Effects

- **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.

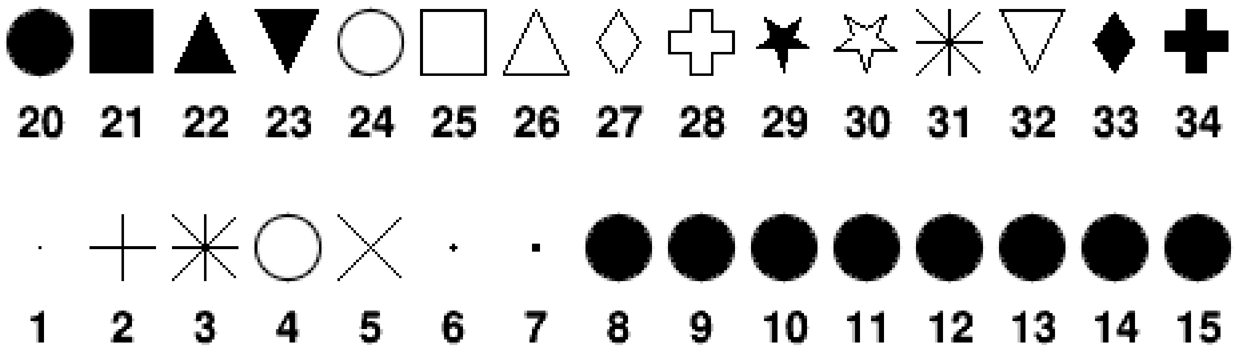
- **Arrows and Lines:** The class representing arrows is TArrow, which inherits from TLine. The constructors of lines and arrows always contain the coordinates of the endpoints.

- **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

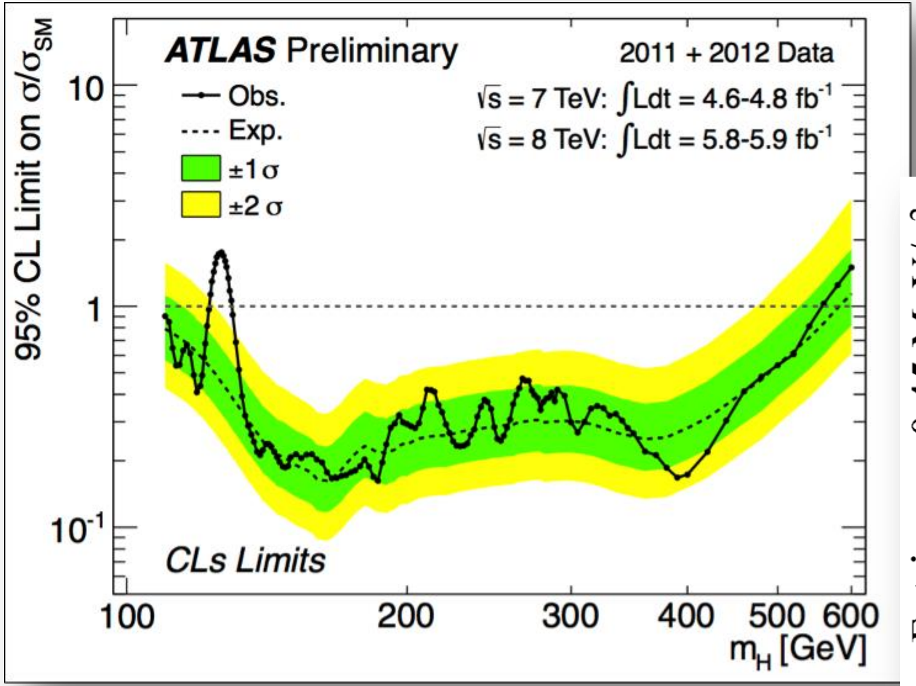
ExampleMacro.C

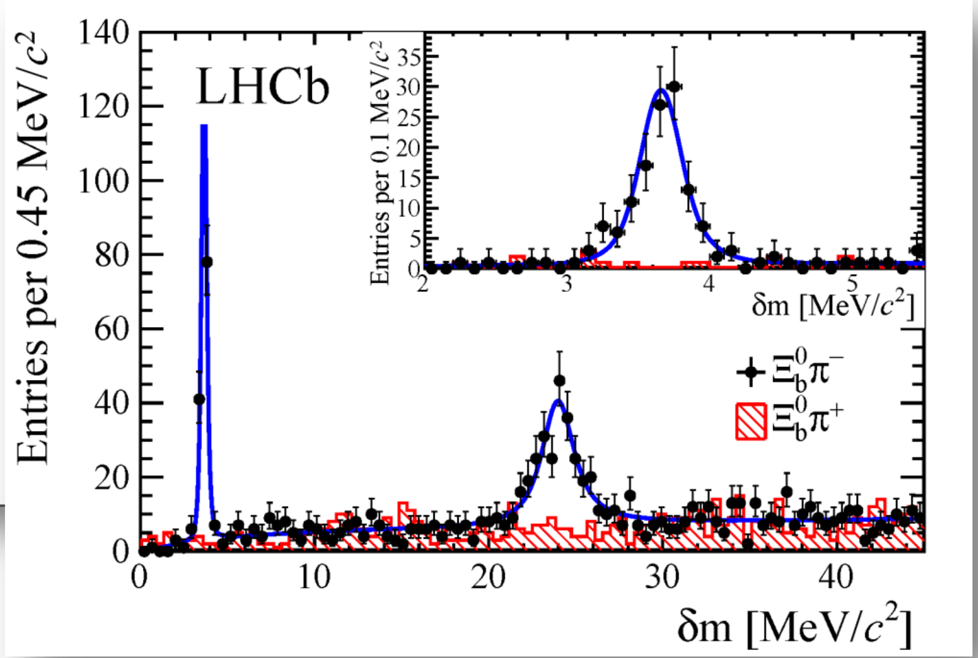
```
int main() {
  ExampleMacro();
  return 0;
}
```

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

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

More about Graphs and Histograms





Graphs

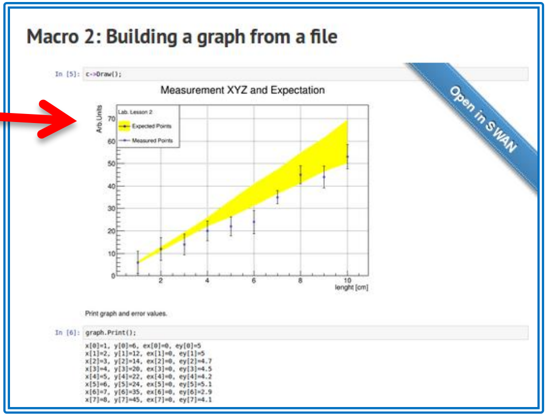
- Read Graph Points from File
- Polar Graphs
- 2D Graphs
- Multiple graphs

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="");
```

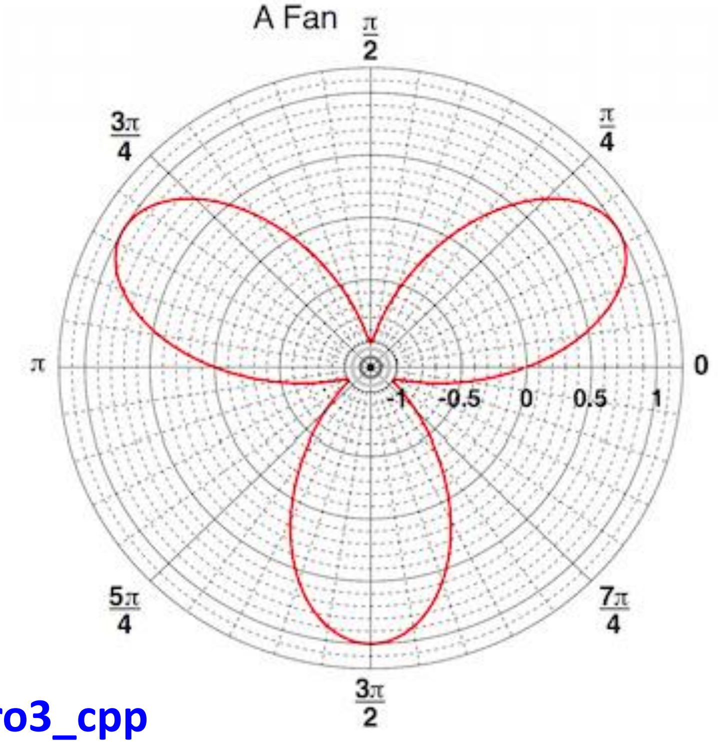
Let's have a look at macro2.C in a notebook (also in section 4.1 of the Primer).

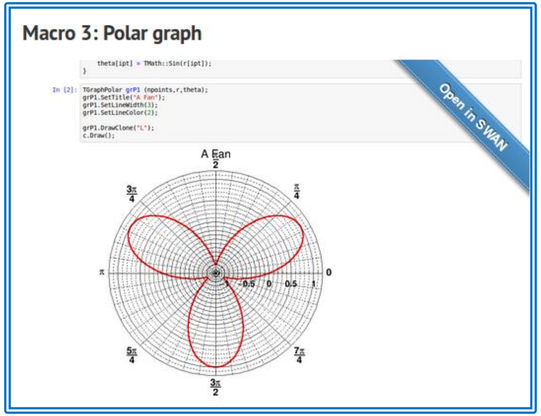


Macro2_cpp

Polar Graphs

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

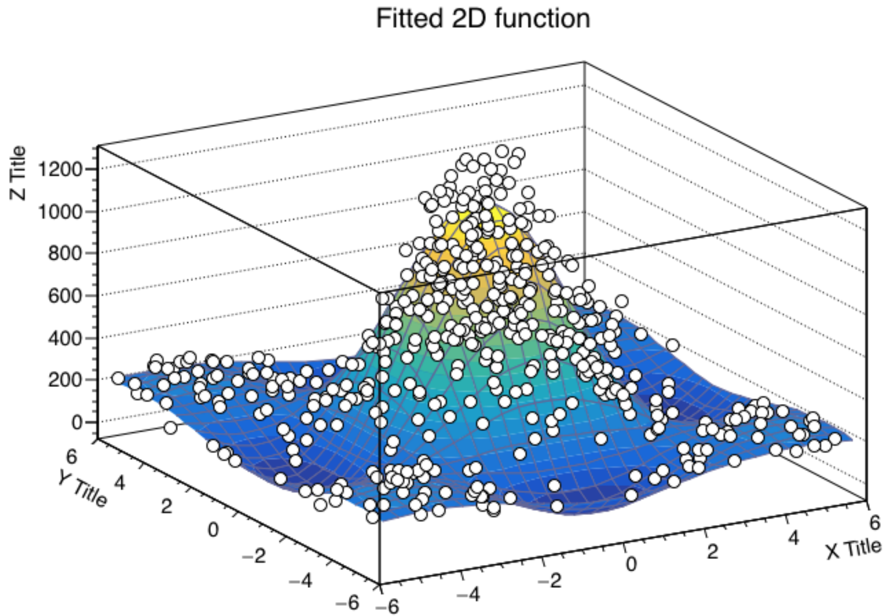


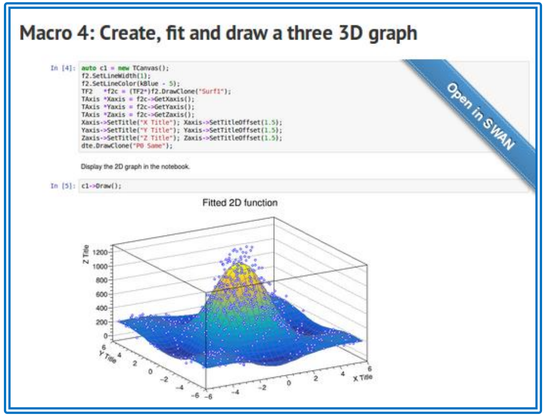


Macro3_cpp

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:

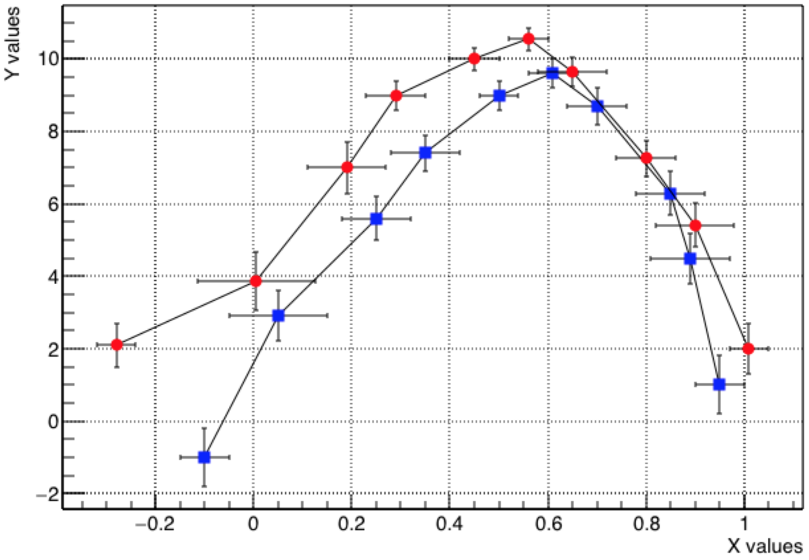


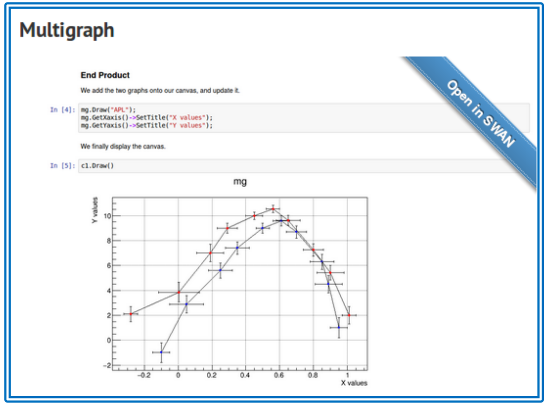


Macro4_cpp

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 (in fact 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)

The solution of this exercise is macro5.C shown in section 5.1 in the Primer

Exercise - Optional

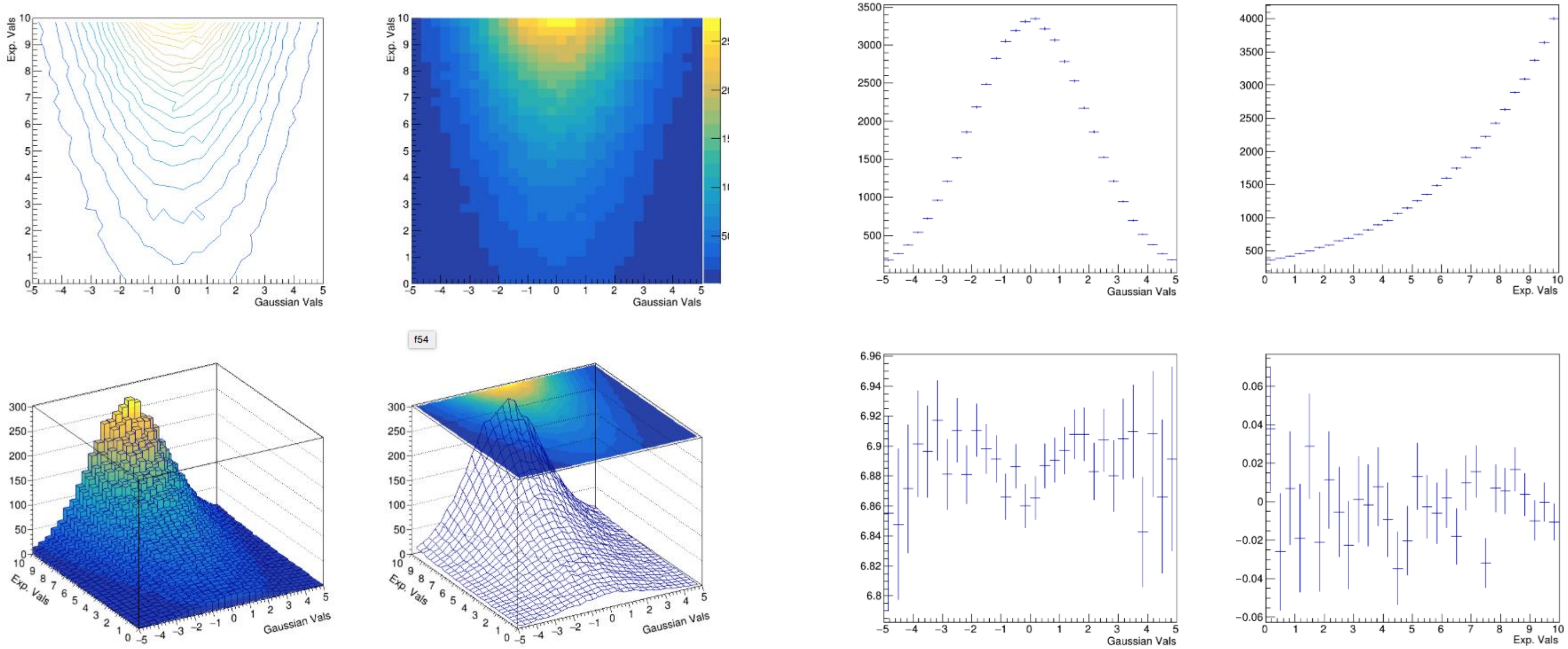
Create a macro that draws the sum, difference and ratio of two histograms

- 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
- Note: for every plot a different canvas has to be created and before drawing, one has to "cd" into it
  - `TCanvas c; c.cd();`

The solution of this exercise is macro6.C shown in section 5.2 in the Primer

Two Dimensional Histograms

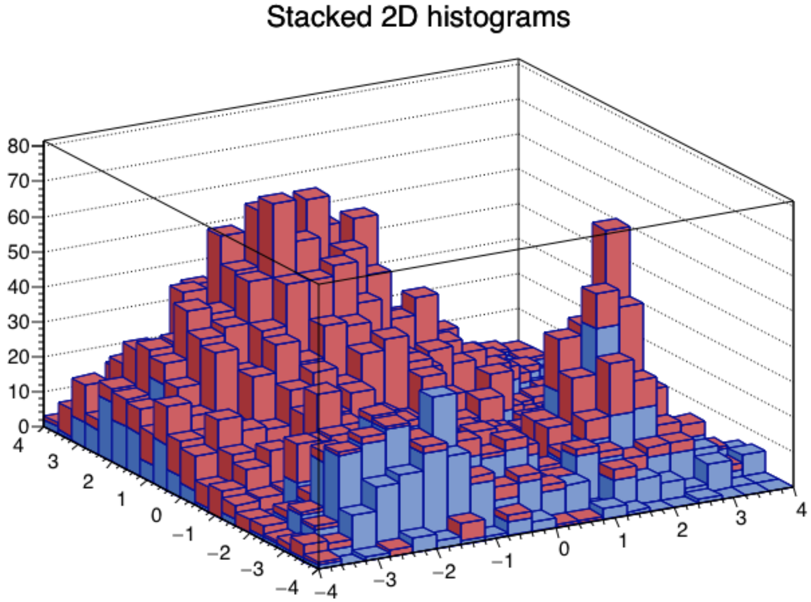
Two-dimensional histograms are a very useful tool, for example to inspect correlations between variables, as in the example in section 5.3 of the Primer (macro7.C):

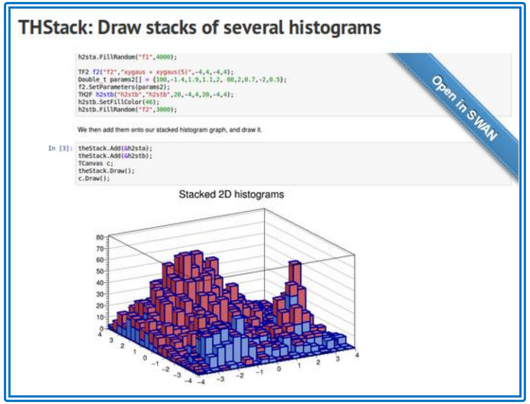


Multiple Histograms

The example in section 5.4 (hstack.C) shows how to group histograms in a single entity call a “stack”.

Class THStack





Hstack_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 (inheriting from TObject) can be written on disk via the Write method.
- Two ways of storing: row wise (single object dump) and column wise (N-tuple like storage).
- Feature widely used, e.g. by all LHC experiments

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

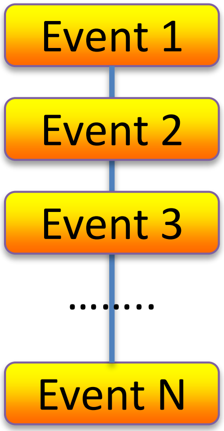
- Create a file copying the lines of the previous slide at the prompt
- Quit the command line interpreter
- Boot ROOT opening the file: root my_rootfile.root
- Type: TBrowser myBrowser
- Inspect the content of the file

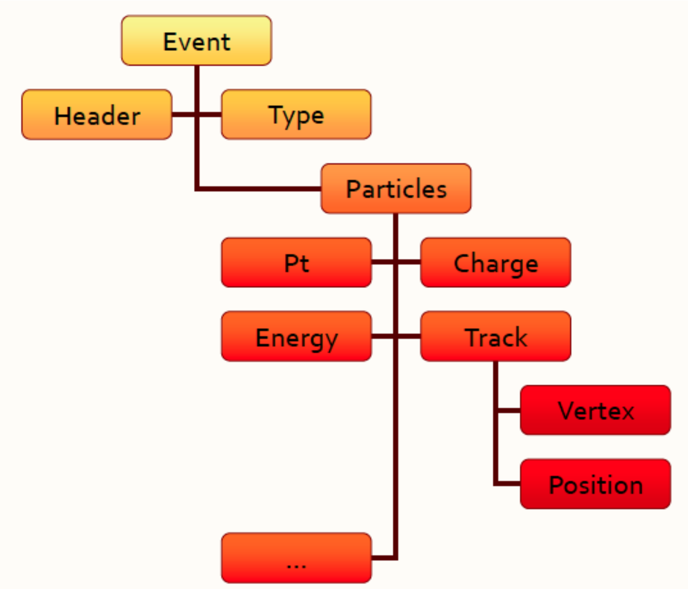
Trees

- 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

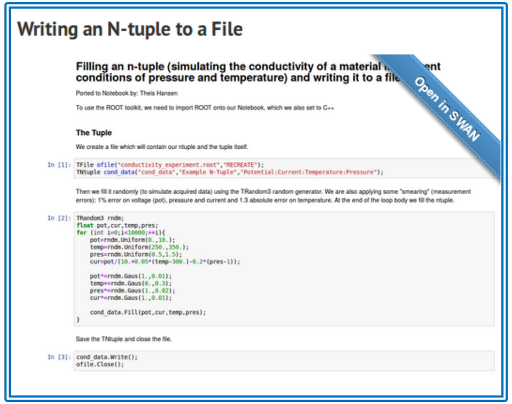
Primer macro (section 7.2.1)
write_ntuple_to_file.C

```
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

- Run the code in SWAN
  - Check your CERNBox for the result file!



Writing an N-tuple to a File

Filling an n-tuple (simulating the conductivity of a material i... ...ent conditions of pressure and temperature) and writing it to a file

Open in SWAN

Ported to Notebook by: Theis Hansen

To use the ROOT toolkit, we need to import ROOT onto our Notebook, which we also set to C++

The Tuple

We create a file which will contain our ntuple and the tuple itself.

```
In [1]: TFile ofile("conductivity_experiment.root","RECREATE");
        TNtuple cond_data("cond_data","Example N-Tuple","Potential:Current:Temperature:Pressure");
```

Then we fill it randomly (to simulate acquired data) using the TRandom3 random generator. We are also applying some "smearing" (measurement errors): 1% error on voltage (pot), pressure and current and 1.3 absolute error on temperature. At the end of the loop body we fill the ntuple.

```
In [2]: TRandom3 rndm;
        float pot,cur,temp,pres;
        for (int i=0;i<10000;++i){
            pot=rndm.Uniform(0.,10.);
            temp=rndm.Uniform(250.,350.);
            pres=rndm.Uniform(0.5,1.5);
            cur=pot/(10.+0.05*(temp-300.)-0.2*(pres-1));

            pot*=rndm.Gaus(1.,0.01);
            temp+=rndm.Gaus(0.,0.3);
            pres*=rndm.Gaus(1.,0.02);
            cur*=rndm.Gaus(1.,0.01);

            cond_data.Fill(pot,cur,temp,pres);
        }
```

Save the TNtuple and close the file.

```
In [3]: cond_data.Write();
        ofile.Close();
```

Write_ntuple_to_file_cpp

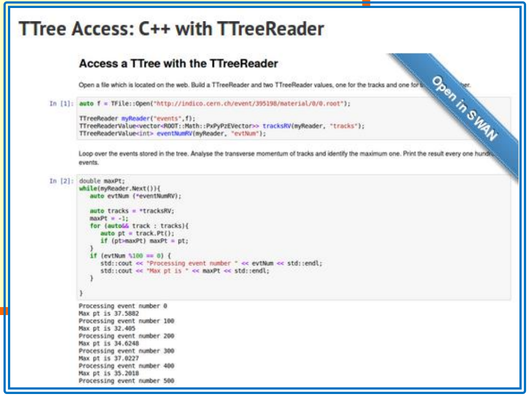
Accessing Complex Trees

- 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, …

Exercise

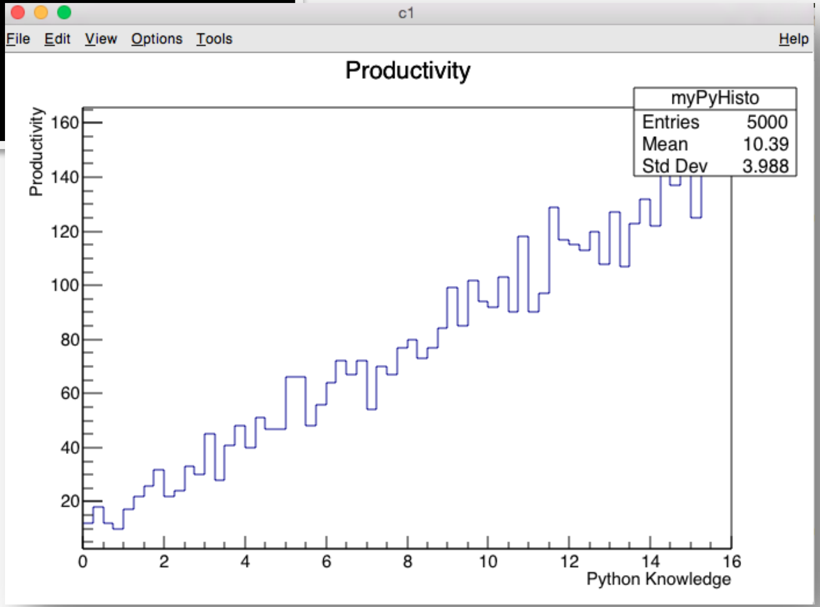
- Open the Python interpreter (type python)
- Import the ROOT module
- Create a histogram with 64 bins and an x axis ranging from 0 to 16
- Fill it with random numbers distributed according to a linear function ("pol0")
- Change its line width with a thicker one
- Draw it!

...or try it in SWAN!

https://swan001.cern.ch

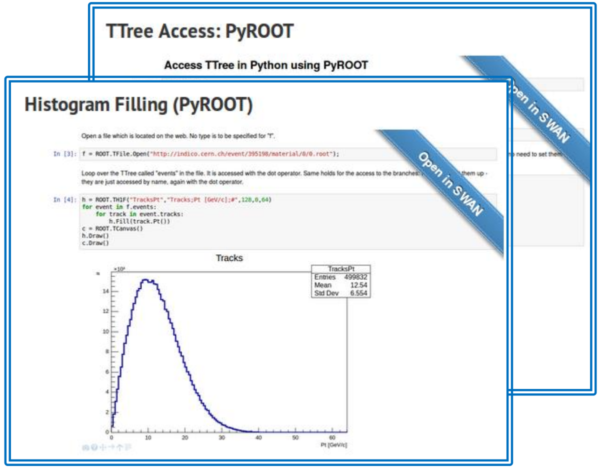
Exercise

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



Exercise

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



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
- Learn about SWAN and Jupyter notebooks