ROOT Summer Student Course

ROOT
Data Analysis Framework
https://root.cern

This course is recorded (slides and audio)

(For the benefit of everybody)

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Physics PhD,
Fellow at ROOT team

My research:
ROOT RDataFrame R&D

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My research:
RNTuple & Histogram R&D

Danilo **Piparo**

ROOT Project Leader

My research:
High performance scientific software and ergonomy of interfaces

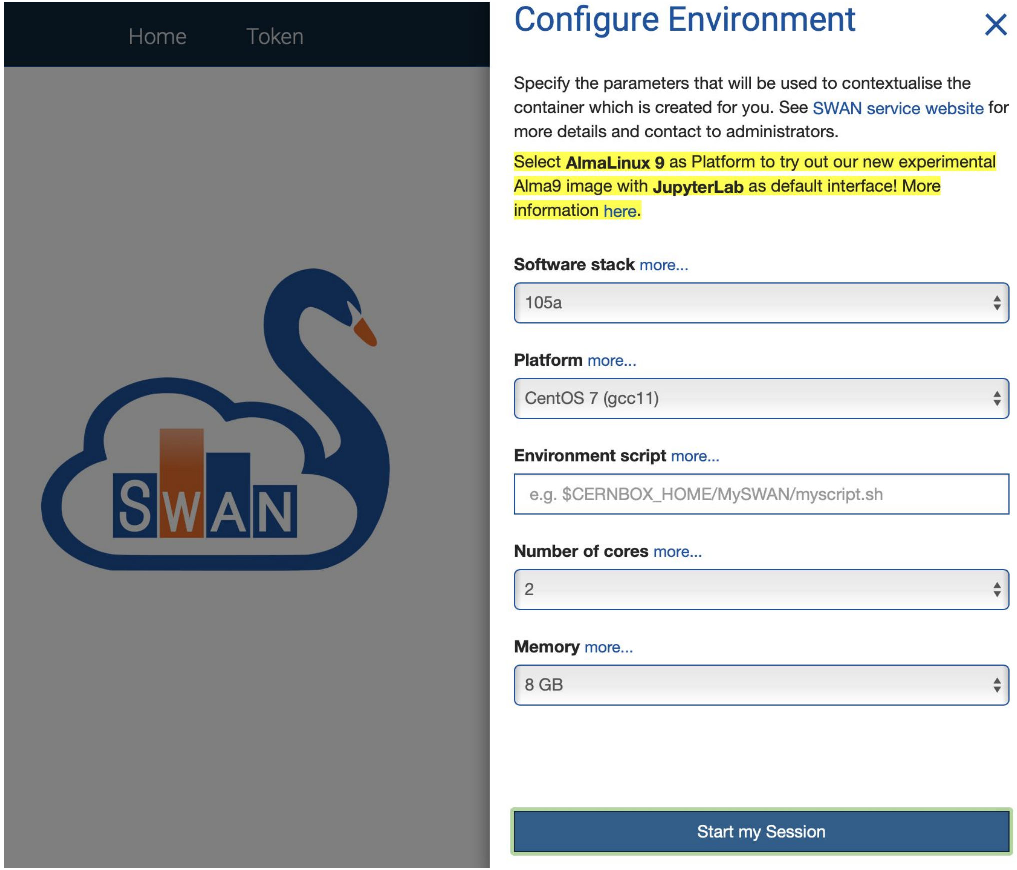
Setup!

Make sure you can login to SWAN: https://swan.cern.ch

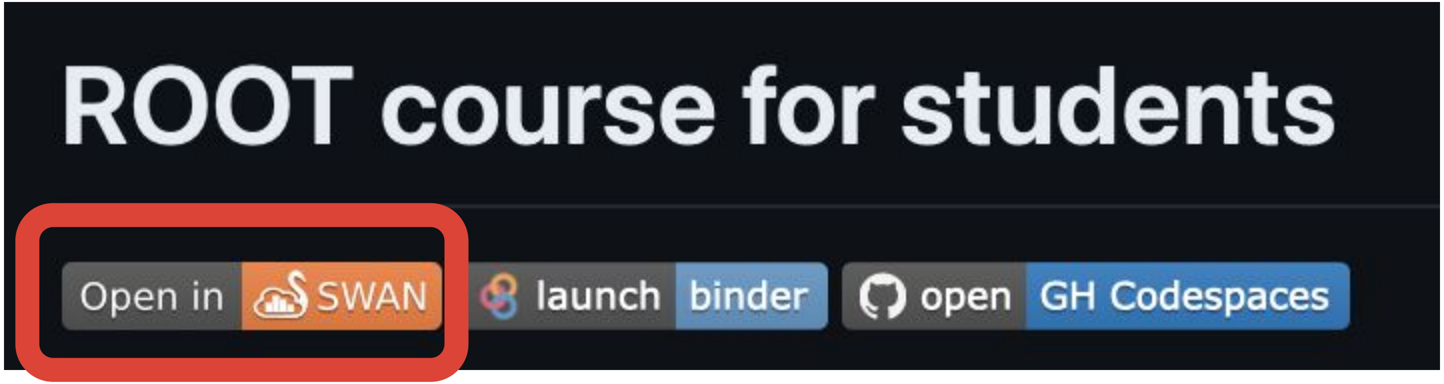
- The Jupyter Notebook service of CERN
- IMPORTANT: first visit https://cernbox.cern.ch

Setup!

Use the SWAN default settings

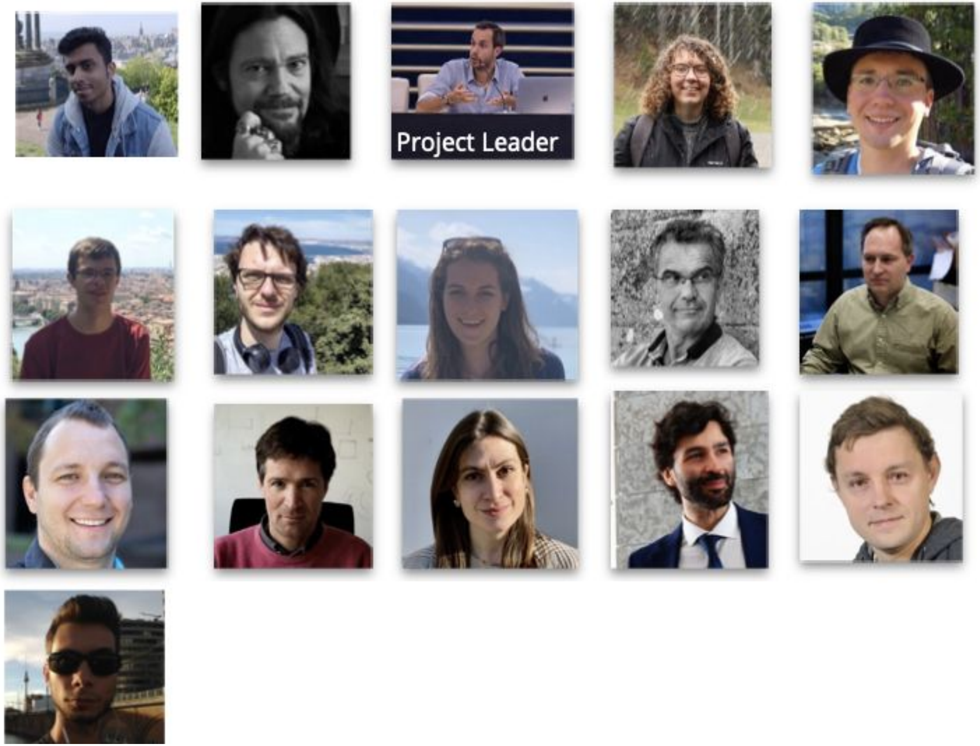


- Go to the [github repository]
- Click on the SWAN badge



Introduction

A Quick Tour of ROOT



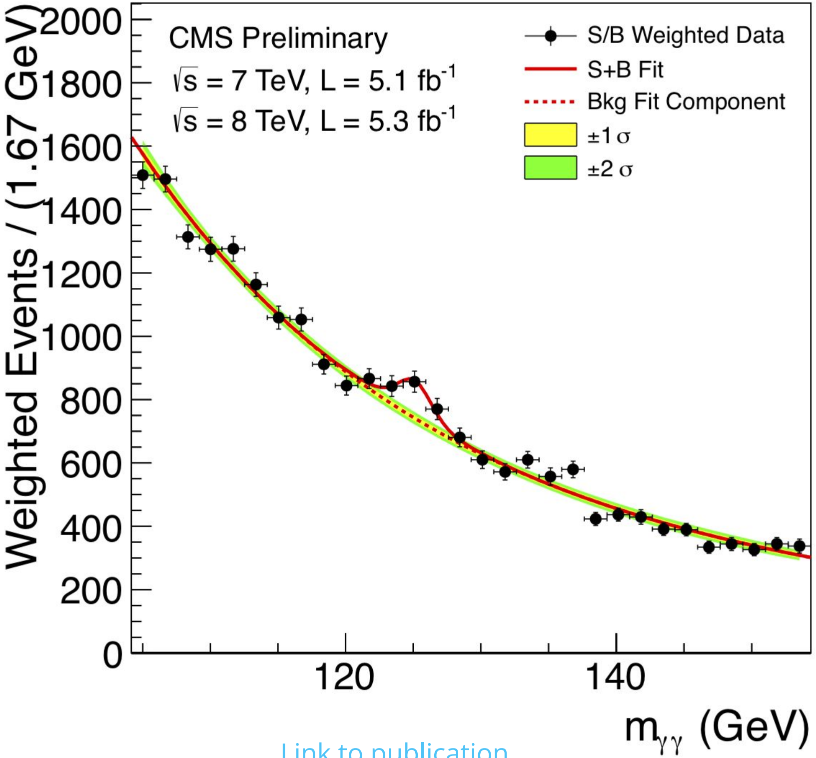
ROOT is an **international collaboration**:

- Large effort contributed by **CERN**
- And also **FNAL**, **GSI**, **Princeton**

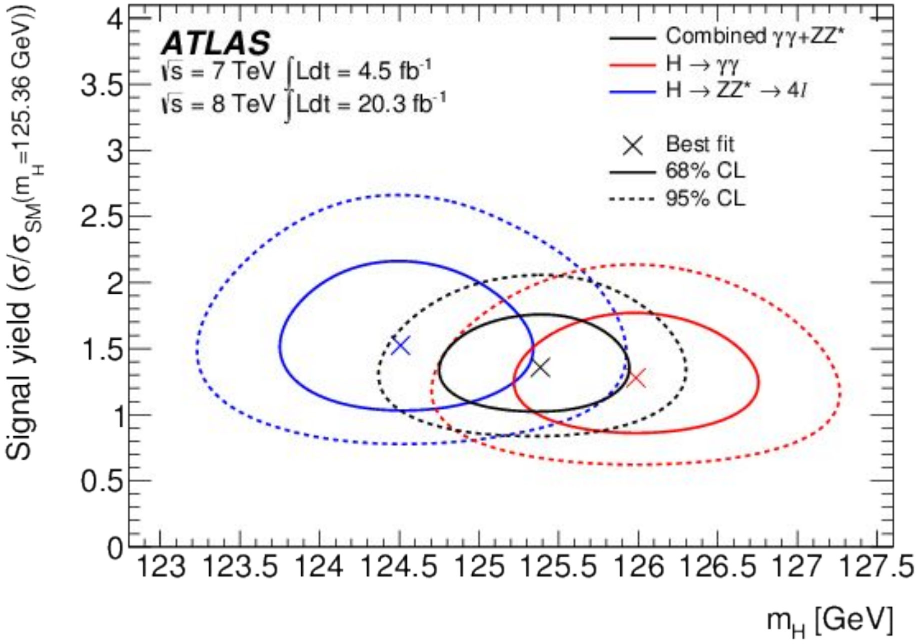
ROOT is its user **community**, **contributors** and **developers**

ROOT is **open source software:** contributions are welcome!

What can you do with ROOT?



Link to publication



Link to publication

ROOT in a Nutshell

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

- **Data analysis: histograms, graphs, functions**
- **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
- **C++ interpretation**: full language compliance
- **Multivariate Analysis** (TMVA): e.g. Boosted decision trees, Neural Nets
- **Advanced graphics** (2D, 3D, event display)
- **Declarative Analysis**: RDataFrame
- And more: HTTP serving, JavaScript visualisation

LGPL 3 Free Software

An Open Source Project

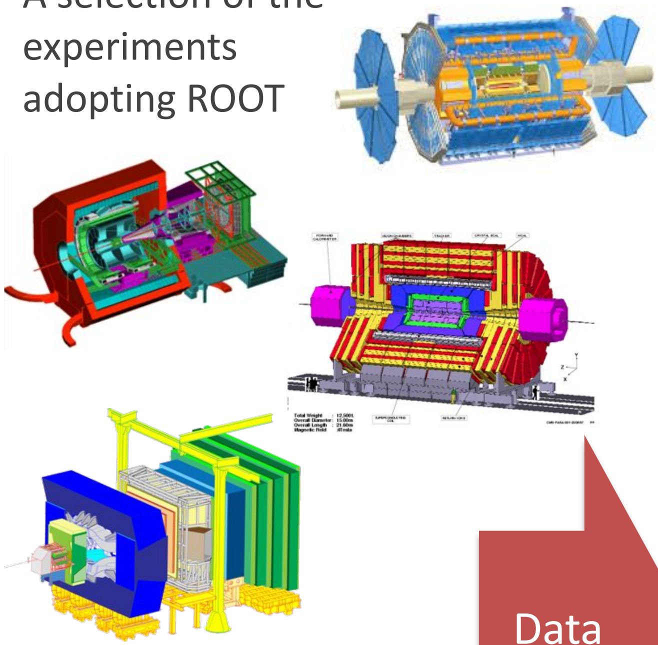
Fork 1.2k Starred 2.3k

Contributors 370

https://github.com/root-project/root

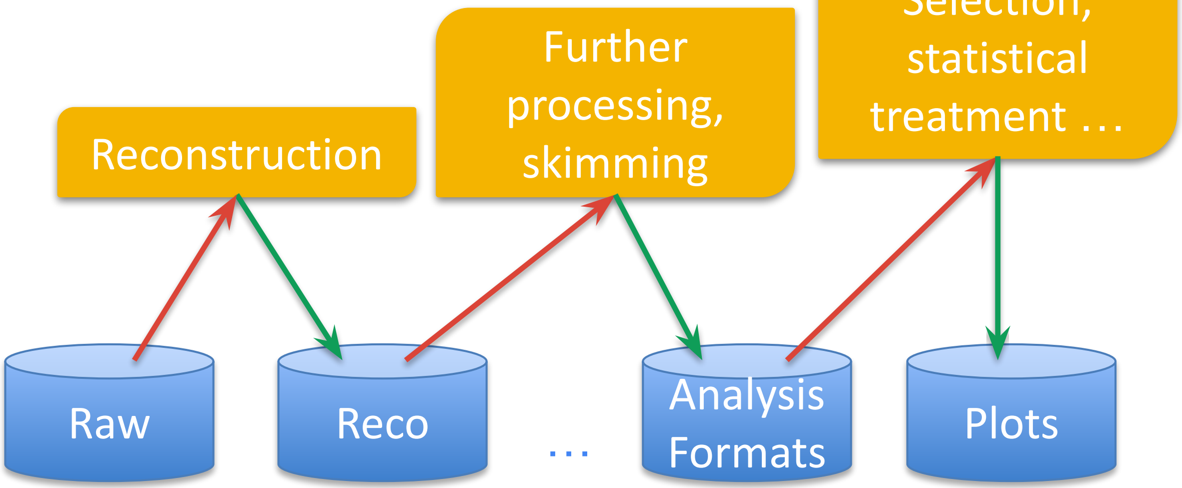
ROOT Application Domains

A selection of the experiments adopting ROOT



Analysis

Offline Processing



Data

Event Filtering

Data Storage: Local, Network

LHC Data in ROOT Format

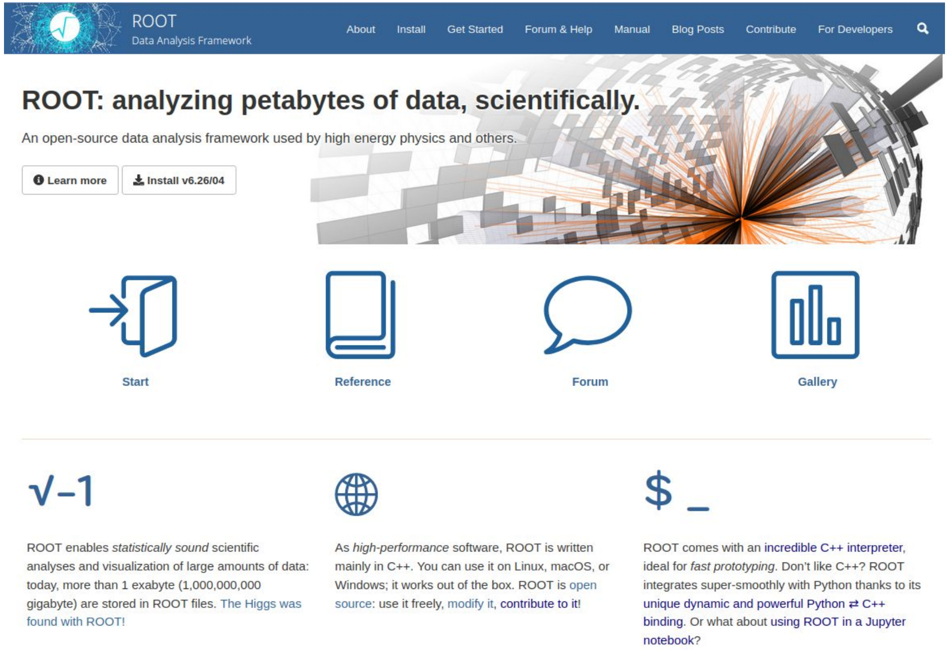
~2EB

(exa = 10^{18})

as of 2024

https://root.cern

- ROOT web site: **the** source of information for ROOT users
  - For beginners and experts
  - Installation instructions
  - Class documentation
  - Manuals, presentations
  - Forum



Resources

- ROOT Forum: https://root-forum.cern.ch
- ROOT Website: https://root.cern
- Further reading: https://root.cern/get_started
  - (includes booklet for beginners: "The ROOT Primer")
- Documentation: https://root.cern/doc/master/

Scope of this Course

- We have 3 hours:
  - Not enough to teach you a HEP analysis
  - Instead, introduction to key elements physicists use from ROOT:
    - **Histogramming**
    - **Fitting**
    - **Reading data**
    - **Data analysis**

Course begins

We now move to the course material on Jupyter Notebooks

Wrap up

Summary

- Covered a number of topics today:
    - What is ROOT and how to use it?
    - How to draw histograms, functions and graphs
    - How to fit histograms
    - How to read and write files
    - What is RDataFrame and how to use it

Have a chat with ROOT!

This course was only the beginning - use the resources, ask us now, ask on the forum!

Or ask us in-person in an informal setting!

Coffee with ROOT

26th June 9:30am-10:30am

R1 - big tables in front of Grab & Go bar

Resources

- ROOT Forum: https://root-forum.cern.ch
- ROOT Website: https://root.cern
- Further reading: https://root.cern/get_started
  - (includes booklet for beginners: "The ROOT Primer")
- Documentation: https://root.cern/doc/master/

GitHub Mattermost

Post-workshop survey

- Thank you for attending the course today!

- At last - we would like to ask you to fill in a **short post-workshop survey** on indico - your opinion matters and we want to make the course even better in the future

Extra material for self study

Foreword

- Most topics (but not all) were already covered in the main part of the course
- Treat the following slides as a good summary of what you’ve already learned plus some extra information
- Additionally, after every sub-module you are pointed to some extra exercises (in the) where you will practice both using notebooks (as during the course), but you will also attempt writing and executing C++ ROOT macros

ENJOY!

The ROOT Prompt and Macros

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 …
    - Code is **Just-in-Time compiled!**
  - Is started with the command:

```
root
```

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

ROOT As a Calculator

$$\frac{1}{1-x} = 1 + x + x^2 + x^3 + x^4 + \ldots$$

$$= \sum_{n=0}^{\infty} x^n$$

ROOT can be used as a simple calculator, but we let's make a step forward: declare **variables** and use a ***for*** control structure.

```
root [0] double x=.5
(double) 0.5
root [1] int N=30
(int) 30
root [2] double gs=0;
```

```
root [3] for (int i=0;i<N;++i) gs += pow(x,i)
root [4] std::abs(gs - (1/(1-x)))
(Double_t) 1.86265e-09
```

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>**
  - **.help** or **.?** gives the full list

ROOT Macros

- 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

- A 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 run by typing:

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

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 also be used to produce standalone, compiled applications:

Advanced Users

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

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

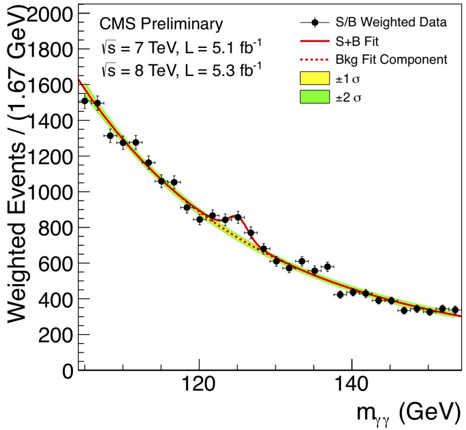
Time For Exercises

- Go to folder: student-course/exercises/extra/00_C++_Interpreter

Histograms, Graphs and Functions

Histograms

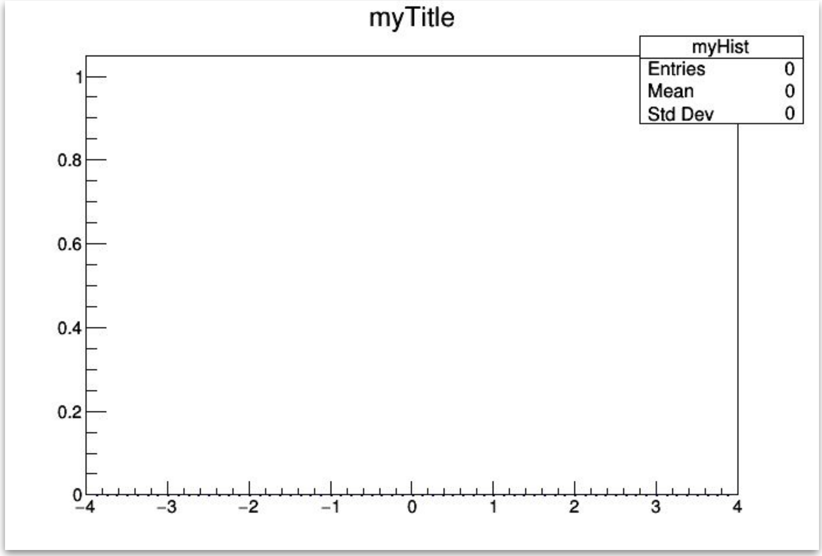
- A simple form of data reduction
  - Can have billions of collisions, the Physics displayed in a few histograms
  - Possible to calculate statistical quantities: mean, rms, skewness, …
- Collect quantities in bins (discrete categories)
- ROOT provides a rich set of histograms
  - Focus on the class **TH1D today**: one dimensional histogram filled with doubles
  - but also available:
    - multiple dimensions histogram **TH{1,2,3}** classes
    - histograms holding different precision types: floats F, integers I, strings S



My First Histogram

C++

```
root [0] TH1D h("myHist", "myTitle", 64, -4, 4)
root [1] h.Draw()
```



Note that in **the SWAN notebooks**: the figure is not shown directly.

You have to:

1. Either call `gPad->Draw()` at the end:

```
In [1]: TH1D h("myHist", "myTitle", 64, -4, 4);
        h.Draw();
        gPad->Draw();
```

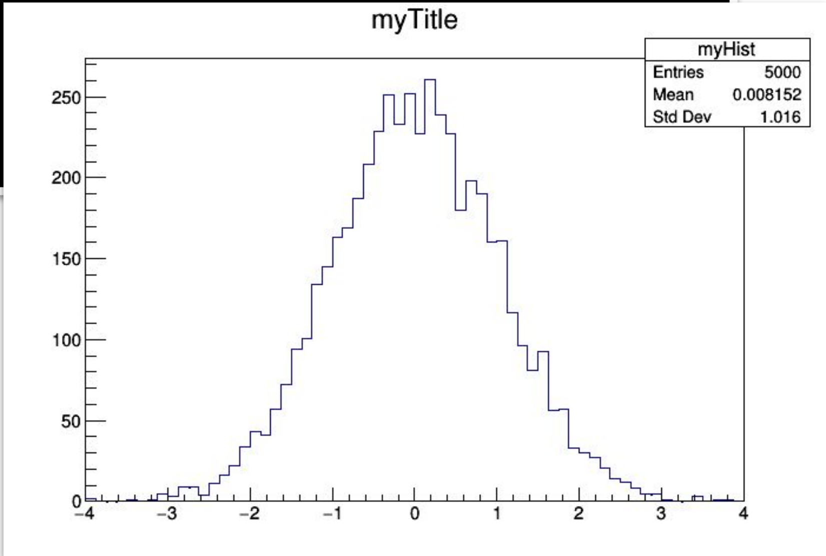
2. Or you can create a `TCanvas` and draw it:

```
In [2]: TCanvas c1;
        TH1D h("myHist", "myTitle", 64, -4, 4);
        h.Draw();
        c1.Draw();
```

My First Histogram

C++

```
root [0] TH1D h("myHist", "myTitle", 64, -4, 4)
root [1] h.FillRandom("gaus")
root [2] h.Draw()
```



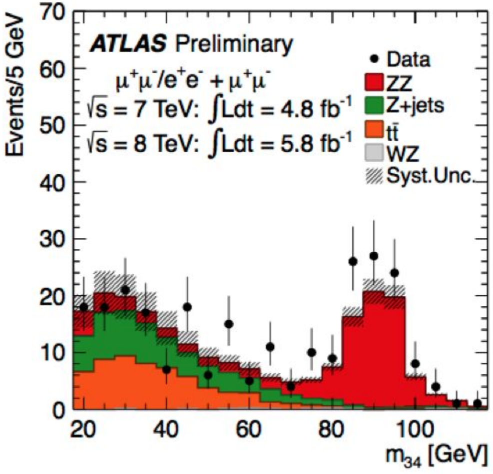
And now in Python!

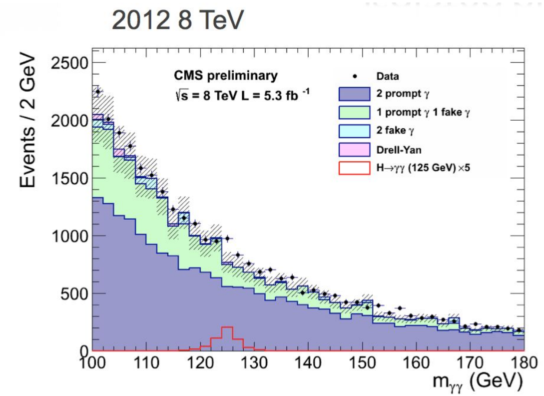
Python

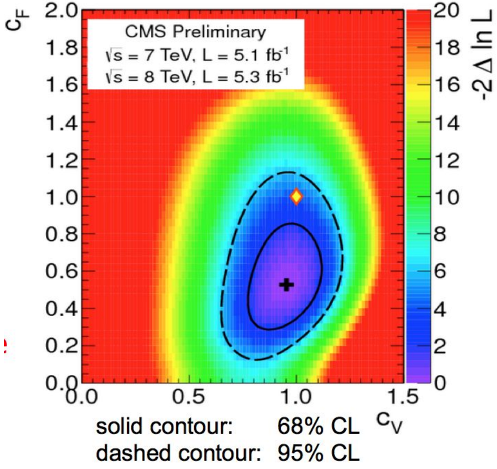
```
> python
>>> import ROOT
>>> h = ROOT.TH1F("myHist", "myTitle", 64,
-4, 4)
>>> h.FillRandom("gaus")
>>> h.Draw()
```

Drawing Options

- See the documentation of the THistPainter class for all possible options on drawing histograms



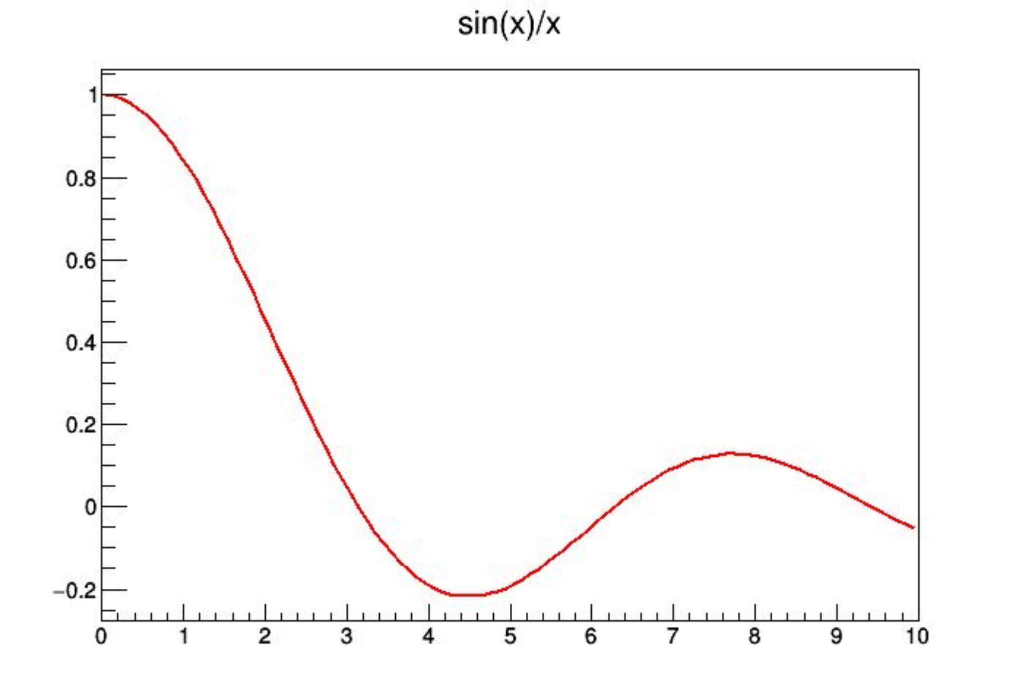




Functions

- Mathematical functions are represented by the **TF1** class
- Functions have **names**, **formulas** and **line properties**
- The **formulas** can be:
  - Mathematical formulas (written as strings)
  - C++ functions/functors/lambdas (highly performant custom functions)
  - Python functions
- Functions can be written with and without **parameters**
  - Crucial for fits and parameter estimation
- Functions (as well as integrals and derivatives of functions) **can be evaluated**

ROOT as a Function Plotter



ROOT as a Function Plotter

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

C++

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

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

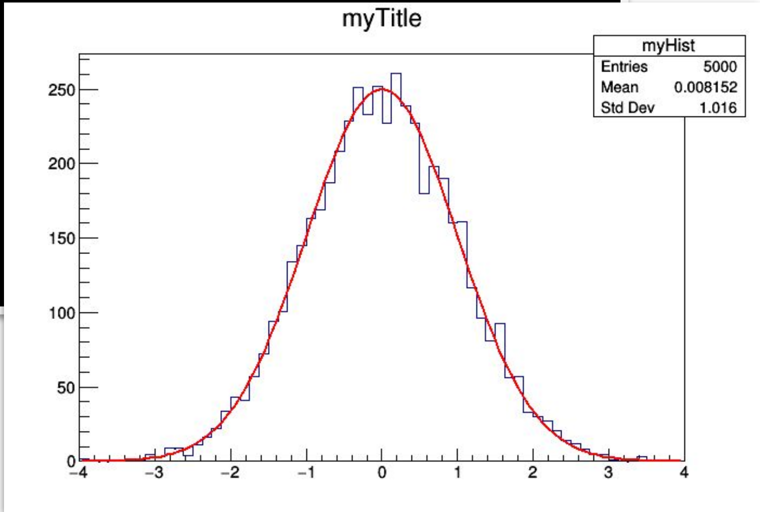
Python

```
>>> f2 = ROOT.TF1("f2","[0]*sin([1]*x)/x",0.,10.)
>>> f2.SetParameters(1,1)
>>> f2.Draw()
```

Another Example: Histogram and function drawn together

C++

```
root [0] TH1D h("myHist", "myTitle", 64, -4, 4)
root [1] h.FillRandom("gaus")
root [2] h.Draw()
root [3] TF1 f("g", "gaus", -8, 8)
root [4] f.SetParameters(250, 0, 1)
root [5] f.Draw("Same")
```

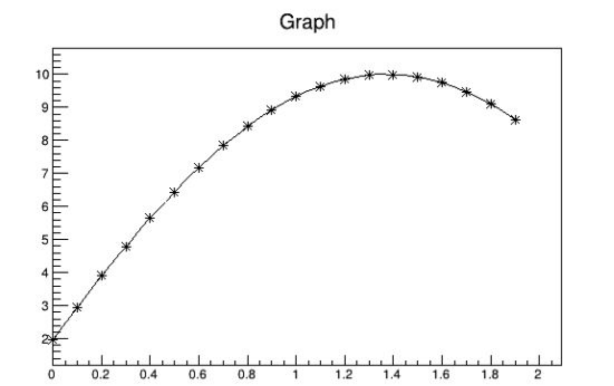


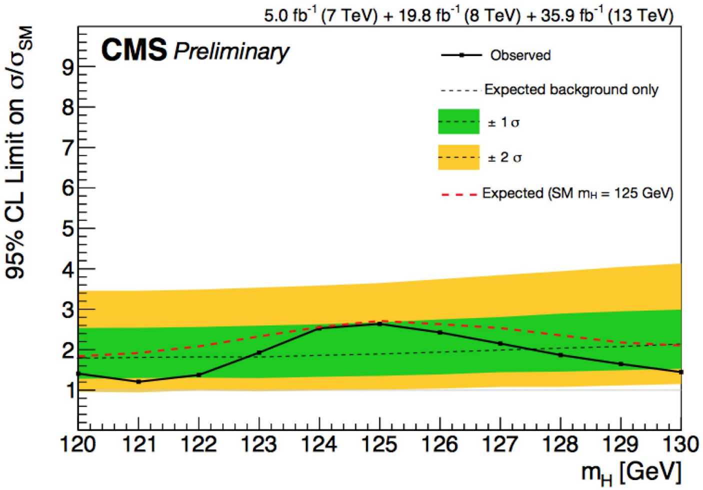
Drawing - important options

option	description
"SAME"	superimpose on top of existing picture
"L"	connect all computed points with a straight line
"C"	connect all computed points with a smooth curve
"FC"	draw a fill area below a smooth curve

[TGraph Painter documentation]

Graphs





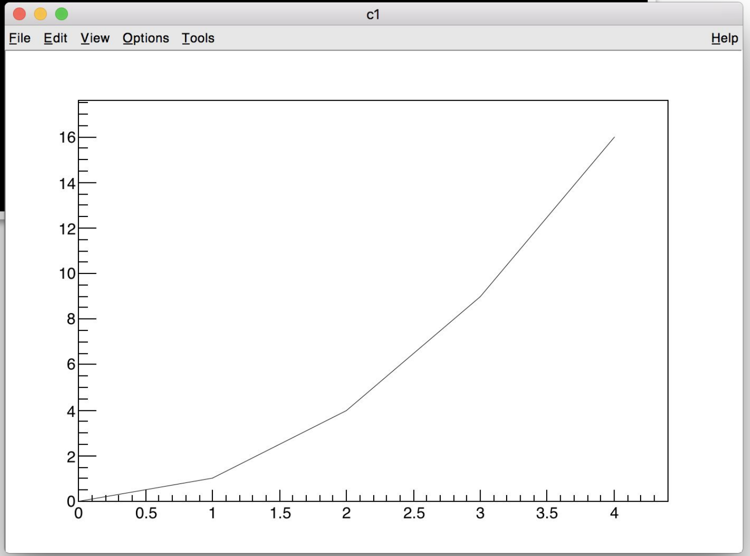
- Display points and associated errors
- **Fundamental to display trends**

[See 132nd LHCC Meeting](#)

My First Graph

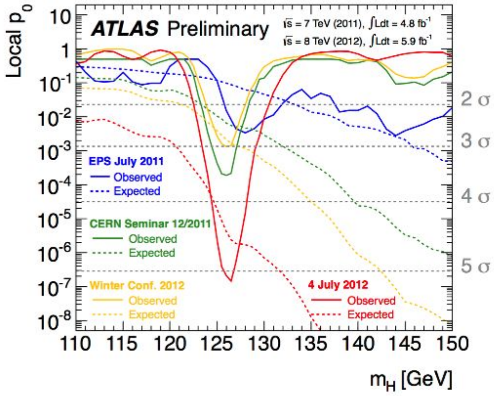
```
>>> g = ROOT.TGraph()
>>> for i in range(5): g.SetPoint(i,i,i*i)
>>> g.Draw("APL")
```

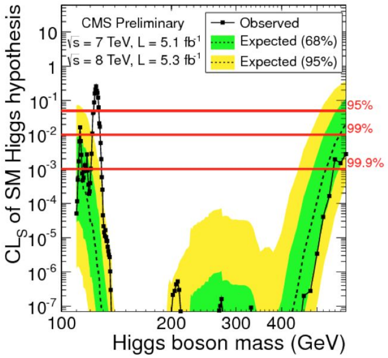
Python

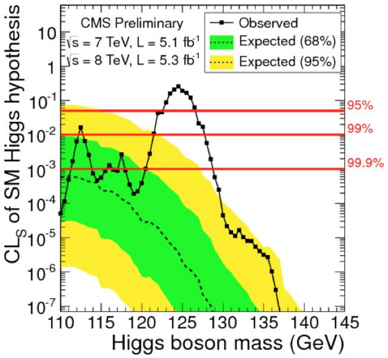


Drawing Options

- See the documentation of TGraphPainter for the Graph drawing options







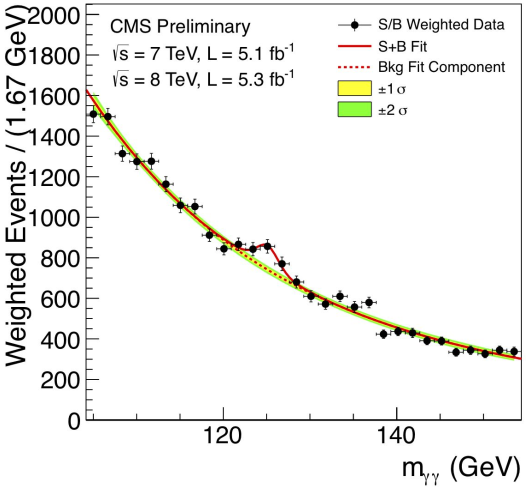
Time For Exercises

- Go to folder: student-course/exercises/extra/01_Histograms_Graphs_Functions

Parameter Estimation and Fitting

What is Fitting ?

- Estimate parameters of a hypothetical distribution from the observed data distribution
  - **y = f (x | θ)** is the fit model function
- Find the best estimate of the parameters **θ** assuming **f (x | θ)**
- Both Likelihood and Chi2 fitting are supported in ROOT



Example

Higgs → γγ spectrum

We can fit for:

- the expected number of Higgs events
- the Higgs mass

Fitting in ROOT

- Create first a **parametric** function object, `TF1`, which represents our model
  - need to set the initial values of the function parameters
  - or use a pre-defined function
- **Fit** the data object (Histogram or Graph):
  - Call the `Fit` method passing the function object
  - various options are possible (see the [`TH1::Fit`]() documentation)
- **Examine** the result:
  - get parameter values, uncertainties, correlation
  - get fit quality estimation
- **Draw** the fit function:
  - automatically, on top of the Histogram or the Graph when calling
    `TH1::Fit` or `TGraph::Fit`

Creating the Fit Function

- Parametric function object (**TF1**) :
  - write formula expressions using functions:

```
TF1 f1("f1","[0]*TMath::Gaus(x,[1],[2])");
```

    - **[0],[1],[2] indicate the parameters.**
    - We could also use meaningful names, like [a],[mean],[sigma]

- Use the available functions in ROOT library
  - Pre-defined functions e.g.: *gaus, expo, landau…*

```
TF1("f1","gaus");
```

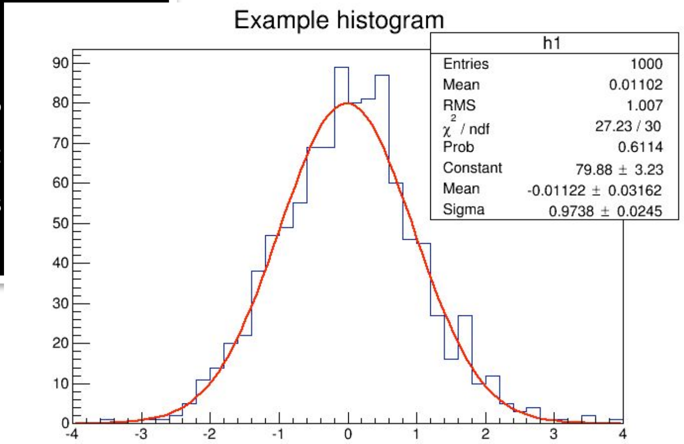
- for more complex examples and fitting options see backup slides
- for full list of functions see the documentation of TH1::Fit(), and the TFormula reference doc

Fitting Histograms example

- We have a histogram, h1, and we want to fit a function to it:

```
root [0] TF1 f1("f1","gaus");
root [1] h1.Fit(&f1);

 FCN=27.2252 FROM MIGRAD    STATUS=CONVERGED      60 CALLS          61 TOTAL
                     EDM=1.12393e-07    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                  STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     7.98760e+01   3.22882e+00   6.64363e-03  -1.55477e-05
   2  Mean        -1.12183e-02   3.16223e-02   8.18642e-05  -1.49026e-02
   3  Sigma        9.73840e-01   2.44738e-02   1.69250e-05  -5.41154e-03
```



For displaying the fit parameters:

```
gStyle->SetOptFit(1111);
```

Minimization

- The fit is done by minimizing the least-square or maximizing the likelihood function.
- A direct solution exists only in case of linear fitting
  - it is done automatically in such cases (e.g fitting polynomials).
- Otherwise an **iterative algorithm** is used:
  - Minuit is the minimization algorithm used by default
    - ROOT provides two implementations*: Minuit and Minuit2
  - To change the minimizer:

```
ROOT::Math::MinimizerOptions::SetDefaultMinimizer("Minuit2");
```

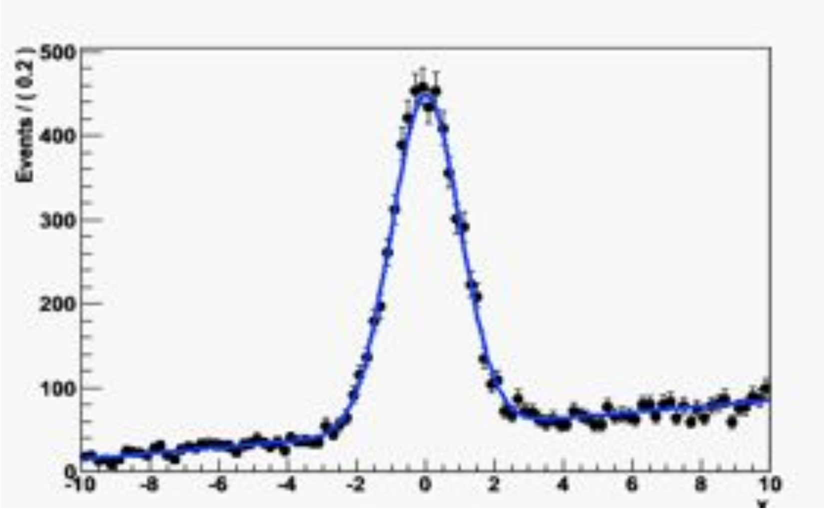
  - Other commands are also available to control the minimization, see [documentation]

*other algorithms exists, for example, Fumili, or minimizers based on GSL (genetic and simulated annealing algorithms)

Fitting - references for the future

RooFit: ROOT toolkit for complex fitting

- ROOT fitting can handle complicated functions but complex models require many lines of code
- **RooFit** provides functionality for building complex fitting models
- Fitting often requires **Normalization** of pdfs
  - not always trivial to perform → RooFit does it automatically
- RooFit also provides:
  - **MC data generation** from model
  - advance **visualization** of fitting results
  - **simultaneous fit** to different data samples
  - full model description for **reusability**
  - **built-in optimization** for optimal computational performances



For more info see the manual or the RooFit courses

TMVA: Machine Learning in ROOT

- ROOT ML tools are provided in **TMVA** (*Toolkit for MultiVariate Analysis*)
- TMVA provides a set of algorithms for standard HEP usage
  - Common interface to different algorithms with consistent evaluation and comparison
  - Capability for classification and regression
  - Embedded in ROOT: **direct connection to input data** (ROOT I/O)
  - Most popular algorithms are BDT and ANN (also supporting some DL tools)
- Interfaces to external ML library :
  - e.g. to Python tools: scikit-learn, Tensorflow/Keras, PyTorch
- Fast inference system for Deep Learning models (SOFIE) and BDT
  - new tool to generate code and easily evaluate ML models in ROOT that can be trained with other tools (e.g Keras, PyTorch) or xgboost
- For more info see the manual

Time For Exercises

- Go to folder: student-course/exercises/extra/02_Fitting
  - plenty of examples – start from the easier ones, continue with more complex

- Note on extras – how to make nice plots:
  - see the backup slides
  - see extra tutorial module, go to folder: student-course/exercises/extra/05_Graphics

Reading and Writing Data

The ROOT File

- In ROOT, objects are written in files*, represented by **TFile** instances
- TFiles are *binary* and can be compressed (transparently for the user)
- **TFiles are self-descriptive**:
  - The information how to retrieve objects from a file is stored with the objects

* this is an understatement - we'll not go into the details in this course!

TFile in Action

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

Option	Description
NEW or CREATE	Create a new file and open it for writing, if the file already exists the file is not opened.
RECREATE	Create a new file, if the file already exists it will be overwritten.
UPDATE	Open an existing file for writing. If no file exists, it is created.
READ	Open an existing file for reading (default).

TFile in Action: Writing

```cpp
TFile f("file.root", "RECREATE");
TH1F h("h", "h", 64, 0, 8);
h.Write("h");
f.Close();
```

C++

- Write to a file
- Close the file and make sure the operation succeeded

```
> rootls -l file.root
TH1F  Jun 24 15:02 2022 h  "h"
```

TFile in Action: Reading

```cpp
TFile f("file.root");
TH1F* h = f.Get<TH1F>("h");
h->Draw();
```

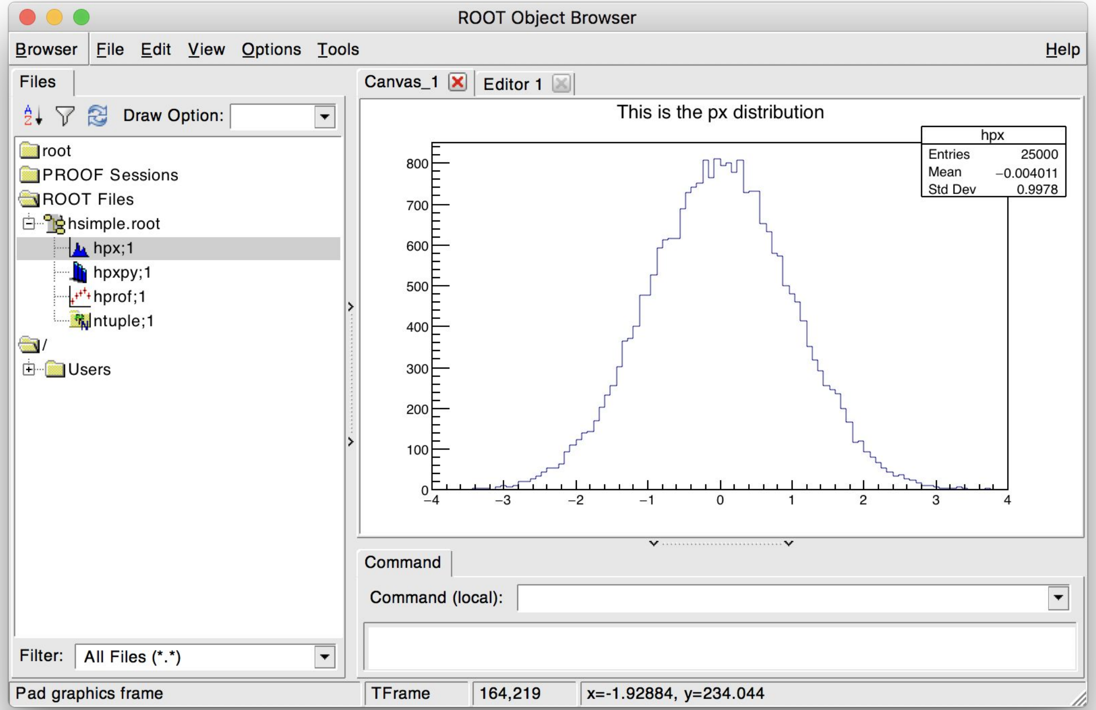
C++

Python

```python
import ROOT
f = ROOT.TFile("file.root")
f.h.Draw()
```

Get the histogram by name!
Possible only in Python

Listing TFile Content



- ***TBrowser*** interactive tool
  > root [0] TBrowser t
- ***rootls*** tool: list content
- ***TFile::ls()***: prints content
  - Great for interactive usage

Time For Exercises

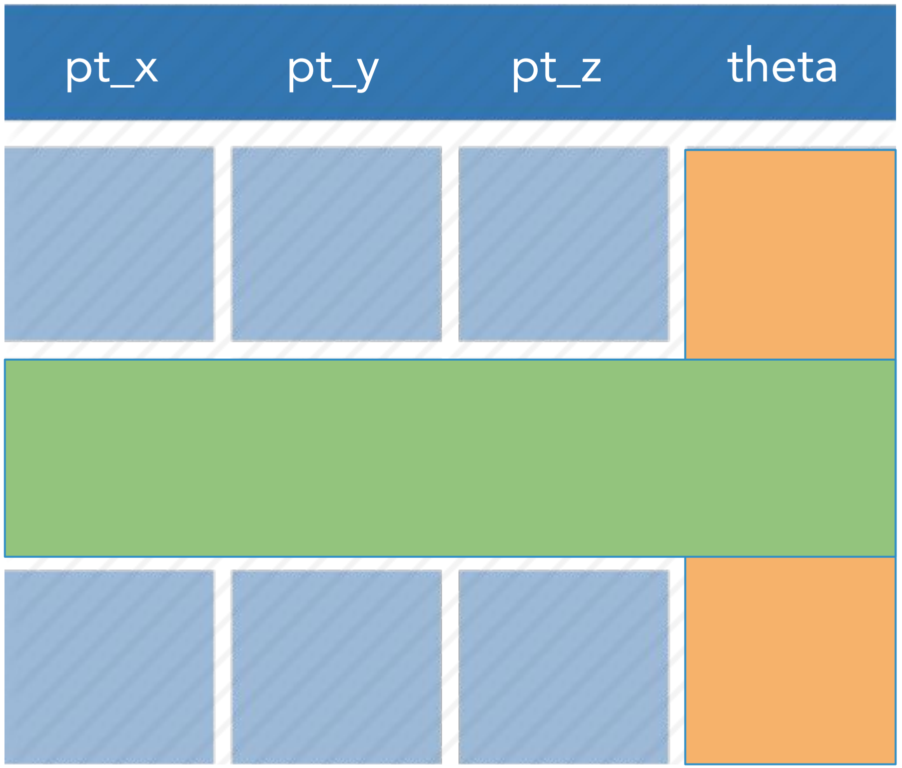
- Go to folder: student-course/exercises/extra/03_Working_With_Files

The ROOT Columnar Format

Columns and Rows

- High Energy Physics: many statistically independent *collision events*
- Create an event class, serialise and write out N instances into a file?
  $\rightarrow$ No. Very inefficient!
- Organise the dataset in **columns**

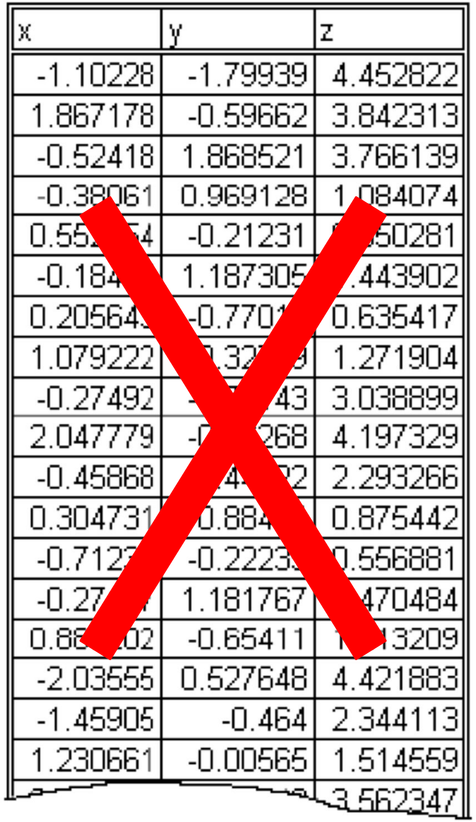
Columnar Representation



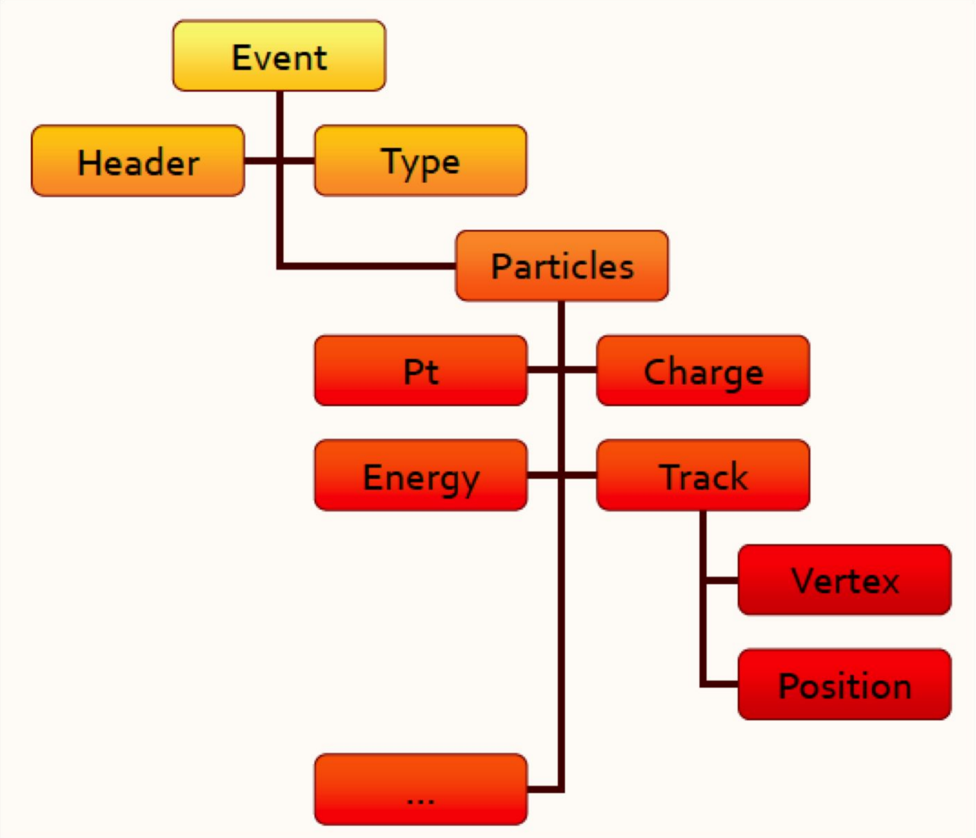
entries
or events
or rows

columns
or "branches"
can contain any kind
of c++ object

Relations Among Columns



x	y	z
-1.10228	-1.79939	4.452822
1.867178	-0.59662	3.842313
-0.52418	1.868521	3.766139
[illegible]	0.969128	[illegible]
[illegible]	-0.21231	[illegible]
[illegible]	1.187305	[illegible]
[illegible]	[illegible]	0.635417
1.079222	[illegible]	1.271904
-0.27492	[illegible]	3.038899
2.047779	[illegible]	4.197329
-0.45868	[illegible]	2.293266
0.304731	[illegible]	0.875442
[illegible]	[illegible]	[illegible]
[illegible]	1.181767	[illegible]
[illegible]	-0.65411	[illegible]
-2.03555	0.527648	4.421883
-1.45905	-0.464	2.344113
1.230661	-0.00565	1.514559
[illegible]	[illegible]	3.562347

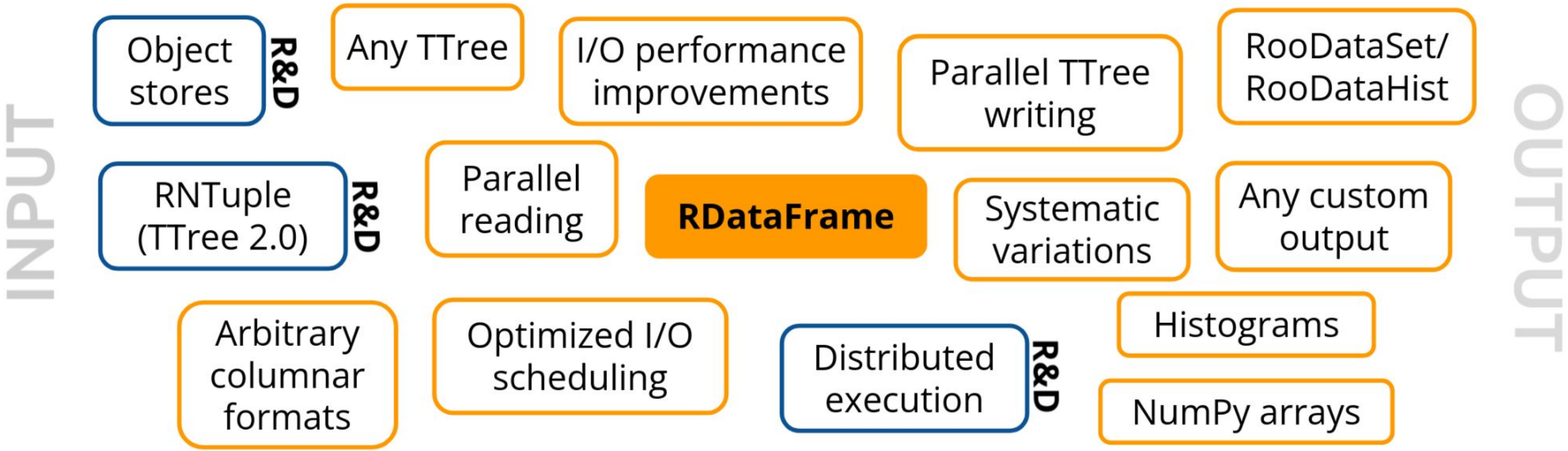


The TTree data format

A columnar dataset in ROOT is represented by the class **TTree**:

- Also called ***tree***, columns also called ***branches***
- Columns can contain **any arbitrary** C++ type

An entry point to modern ROOT



RDataFrame: quick how-to

1. build a data-frame object by specifying your data-set
2. apply a series of transformations to your data
   - filter (e.g. apply some cuts) or
   - define new columns
3. apply actions to the transformed data to produce results (e.g. fill a histogram)

Simple Code Example

1. Build RDataFrame

```python
import ROOT
df = ROOT.RDataFrame("t", "f.root")
h = df.Filter("theta > 0").Histo1D("pt")
h.Draw()
```

Lazily build computation graph ← `df = ...`, `h = ...`

Trigger execution ← `h.Draw()`

2. Cut on theta

3. Fill histogram with pt

Filling multiple histograms

```
h1 = df.Filter("theta > 0").Histo1D("pt")
h2 = df.Filter("theta < 0").Histo1D("pt")
h1.Draw()          // event loop is run lazily once here
h2.Draw("SAME")    // no need to run loop again here
```

Book all your actions upfront. The first time a result is accessed, RDataFrame will fill all booked results.

More on histograms

```
h = df.Histo1D(("myName", "Title;x", 10, 0., 1.),"x")
```

You can specify a model histogram with

- a name and a title
- a predefined axis range

Here, the histogram is created with 10 bins ranging from 0 to 1, and the axis is labelled "x".

Define a new column

```
m = (
    df.Filter("x > y")
      .Define("z", "sqrt(x*x + y*y)")
      .Mean("z")
)
```

`Define` takes the name of the new column and its expression. Later you can use the new column as if it was present in your data.

Working with collections

```
h = df.Define(
      "good_pt",
      "sqrt(px*px + py*py)[E>100]"
).Histo1D("good_pt")
```

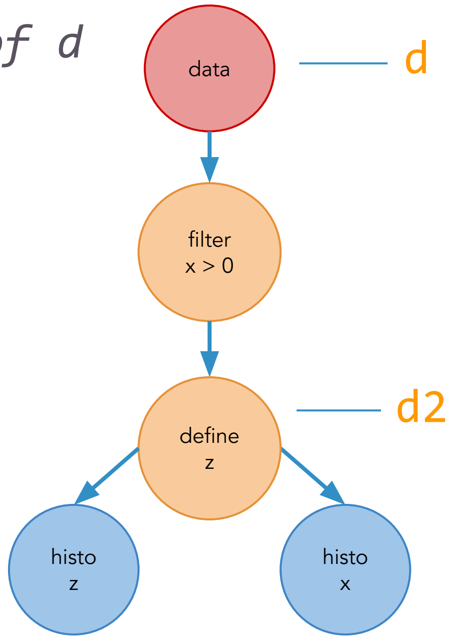
sqrt(px*px + py*py)[E>100]:

- px, py and E are columns the elements of which are RVecs
- Operations on RVecs like sum, product, sqrt preserve the dimensionality of the array
- [E>100] selects the elements of the array that satisfy the condition
- E > 100: boolean expressions on RVecs such as E > 100 return a mask, that is an array with information on which values pass the selection (e.g. [0, 1, 0, 0] if only the second element satisfies the condition)

Think of your analysis as data-flow

```cpp
// d2 is a new data-frame, a transformed version of d
auto d2 = d.Filter("x > 0")
           .Define("z", "x*x + y*y");

// make multiple histograms out of it
auto hz = d2.Histo1D("z");
auto hx = d2.Histo1D("x");
```



You can store transformed data-frames in variables, then use them as you would use an RDataFrame.

Cutflow reports

```
df = (df.Filter("x > 0", "xcut")
        .Filter("y < 2", "ycut"))
df.Report().Print()
```

```
// output
xcut        : pass=49          all=100        --   49.000 %
ycut        : pass=22          all=49         --   44.898 %
```

When called on the main RDF object, `Report` prints statistics for all filters *with a name*

Saving data to file

```
new_df = (
    df.Filter("x > 0")
      .Define("z", "sqrt(x*x + y*y)")
      .Snapshot("tree", "newfile.root")
)
```

We filter the data, add a new column, and then save everything to file. No boilerplate code at all.

Using callables instead of strings

Expert Feature

```
// define a c++11 lambda - an inline function - that checks "x>0"
auto IsPos = [](double x) { return x > 0.; };
// pass it to the filter together with a list of branch names
auto h = df.Filter(IsPos, {"theta"}).Histo1D("pt");
h->Draw();
```

any callable (function, lambda, functor class) can be used as a filter, as long as it returns a boolean

RDataFrame: declarative analyses

```
df = ROOT.RDataFrame("t", "f.root")
df = df.Define("dphi",
               "MyDeltaPhi(phi1, phi2)")
h = df.Histo1D("dphi")
h.Draw()
```

- full control over *the analysis*
- no boilerplate
- common tasks are not already implemented?
- parallelization is not trivial?

RDataFrame: parallelism

```
ROOT.EnableImplicitMT()
df = ROOT.RDataFrame("t", "f.root")
df = df.Define("dphi",
               "ROOT::VecOps::DeltaPhi(phi1, phi2)")
h = df.Histo1D("dphi")
h.Draw()
```

- full control over *the analysis*
- no boilerplate
- common tasks are already implemented
- parallelization is trivial

C++ / JIT / PyROOT

C++ and just-in-time compiled code

```
d.Filter("th > 0").Snapshot("t","f.root","pt*");
```

PyROOT -- just leave out the `;`

```
d.Filter("th > 0").Snapshot("t","f.root","pt*")
```

Time For Exercises

- Go to folder: student-course/exercises/extra/04_RDataFrame

Backup - fitting details

Building More Complex Functions

- Any C++ object (functor) implementing

```
double operator() (double *x, double *p)
```

```
struct Function {
      double operator() (double *x, double *p){
        return p[0]*TMath::Gaus(x[0],p[1],p[2]);
      }
};

Function f;
TF1 f1("f1",f,xmin,xmax,npar);
```

- also a lambda function (with Cling and C++-11)

```
TF1 f1("f1",[](double *x, double *p){return p[0]*x[0];},0,10,1);
```

a lambda can be used also as a string expression, which will be JIT'ed by CLING

```
TF1 f1("f1","[](double *x, double *p){return p[0]*x[0];}",0,10,1);
```

Functionality provided by TFormula

TFormula is based on Cling. Additional functionality provided:

- better parameter definition
  - `TF1("f1","gaus(x, [Constant],[Mean],[Sigma])");`
- function composition by concatenating expressions
  - `TF1 fs("sigma","[0]*x+[1]");`
  - `TF1 f1("f1","gaus(x,[C],[Mean],sigma(x,[A],[B])");`
- normalized sum for component fitting
  - `TF1 model("model","NSUM(expo, gaus)"`
- convolutions
  - `TF1 voigt("voigt", "CONV(breitwiegner, gaus)", xmin, xmax);`
- can define vectorized functions for faster fitting and evaluation
  - see vectorizedFit tutorial
- support for auto-differentiation (automatic generation of gradient and Hessian)

Fitting Options

- Likelihood fit for histograms
  - option "L" for count histograms;
  - option "WL" in case of weighted counts.

```
h1->Fit("gaus","L");
h1->Fit("gaus","LW");
```

- Default is chi-square with observed errors (and skipping empty bins)
  - option "P" for Pearson chi-square

    expected errors, and including empty bins

```
h1->Fit("gaus","P");
```

- Use integral function of the function in bin

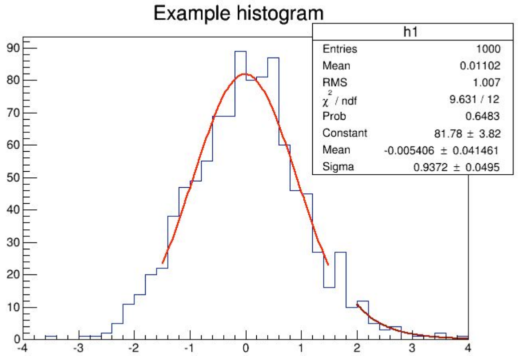
```
h1->Fit("gaus","L I");
```

- Compute MINOS errors : option "E"

```
h1->Fit("gaus","L E");
```

Some More Fitting Options

- Fitting in a Range
  - ```
    h1->Fit("gaus","","",-1.5,1.5);
    ```
- For doing several fits
  - ```
    h1->Fit("expo","+","",2.,4);
    ```
- Quiet / Verbose: option "Q"/"V"
  - ```
    h1->Fit("gaus","V");
    ```
- Avoid storing and drawing fit function (useful when fitting many times)
  - ```
    h1->Fit("gaus","L N 0");
    ```
- Save result of the fit, option "S"
  - ```
    auto result = h1->Fit("gaus","L S");
    result->Print("V");
    ```



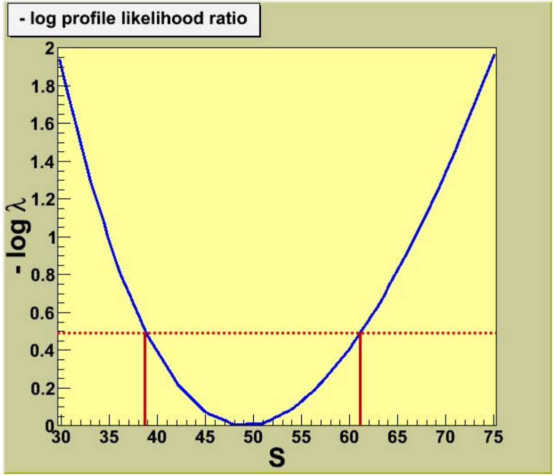
All fitting options documented in reference guide or Manual
    ```

Parameter Errors

Errors returned by the fit are computed from the second derivatives of the log-likelihood function

- Assume the negative log-likelihood function is a parabola around minimum
- This is true asymptotically and in this case the parameter estimates are also normally distributed.
- The estimated correlation matrix is then:

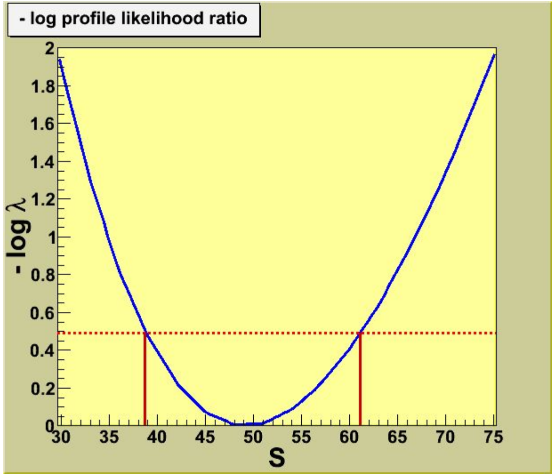
$$\hat{\mathbf{V}}(\hat{\boldsymbol{\theta}}) = \left[\left(-\frac{\partial^2 \ln L(\mathbf{x};\boldsymbol{\theta})}{\partial^2 \boldsymbol{\theta}} \right)_{\boldsymbol{\theta}=\hat{\boldsymbol{\theta}}} \right]^{-1} = \mathbf{H}^{-1}$$



Parameter Errors

- A better approximation to estimate the confidence level of the parameter is to use directly the log-likelihood function and look at the difference from the minimum.
  - Method of Minuit/Minos (Fit option "E")
    - obtain a confidence interval which is in general not symmetric around the best parameter estimate

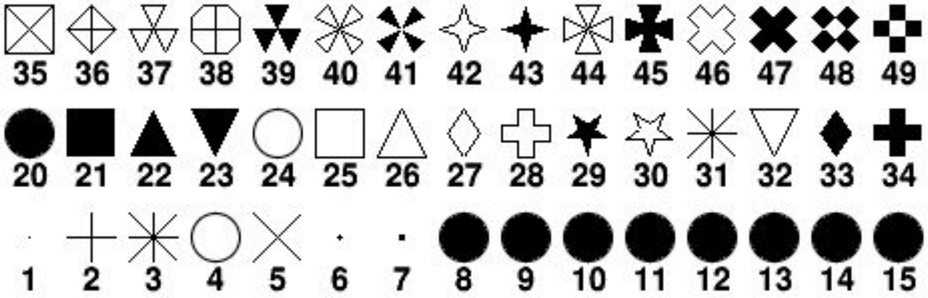
```
auto r = h1->Fit(f1,"E S");
r->LowerError(par_number);
r->UpperError(par_number);
```



Backup - Creating a Nice Plot Survival Kit

The Markers

From the TAttMarker documentation:
https://root.cern/doc/master/classTAttMarker.html

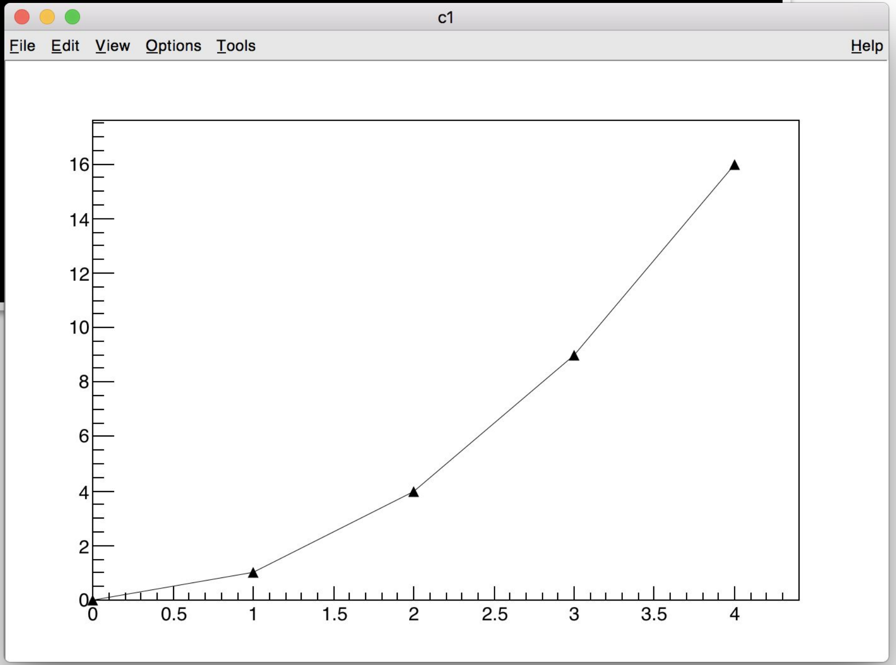



```
kDot=1, kPlus, kStar, kCircle=4, kMultiply=5,
kFullDotSmall=6, kFullDotMedium=7, kFullDotLarge=8,
kFullCircle=20, kFullSquare=21, kFullTriangleUp=22,
kFullTriangleDown=23, kOpenCircle=24, kOpenSquare=25,
kOpenTriangleUp=26, kOpenDiamond=27, kOpenCross=28,
kFullStar=29, kOpenStar=30, kOpenTriangleDown=32,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

Also available through more friendly names ☺

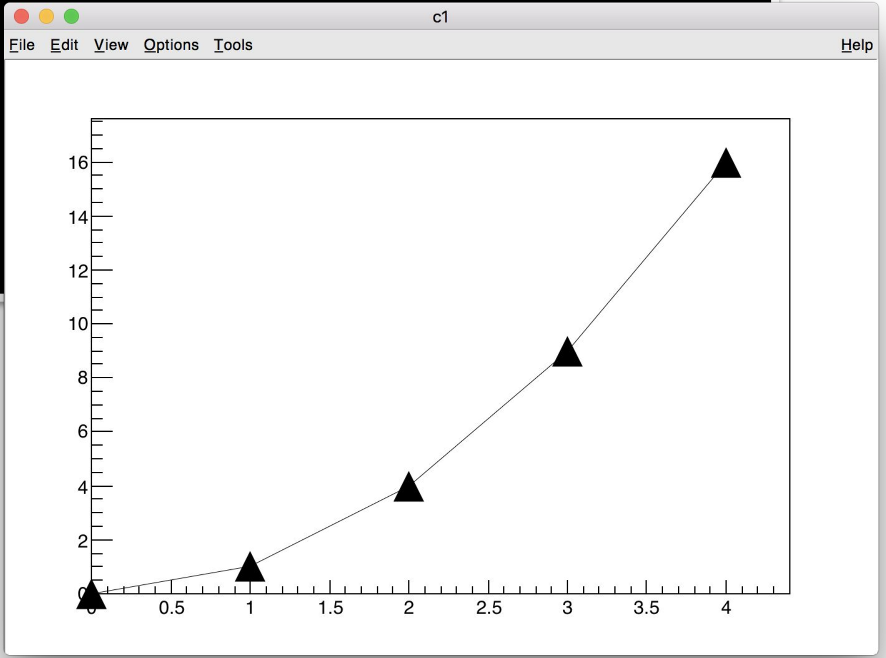
My First Graph

```
root [3] g.SetMarkerStyle(kFullTriangleUp)
```



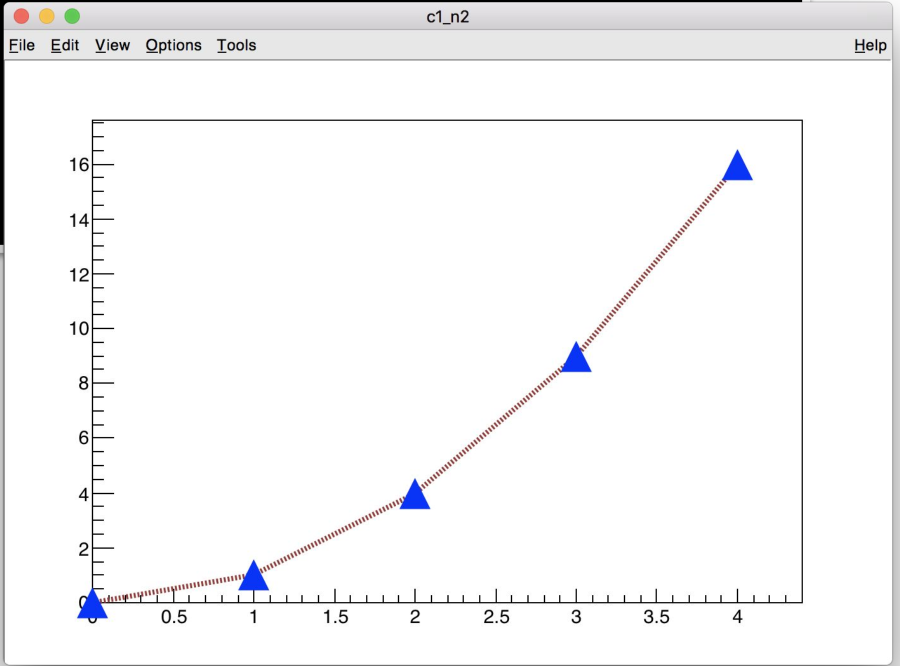
My First Graph

```
root [3] g.SetMarkerStyle(kFullTriangleUp)
root [4] g.SetMarkerSize(3)
```



My First Graph

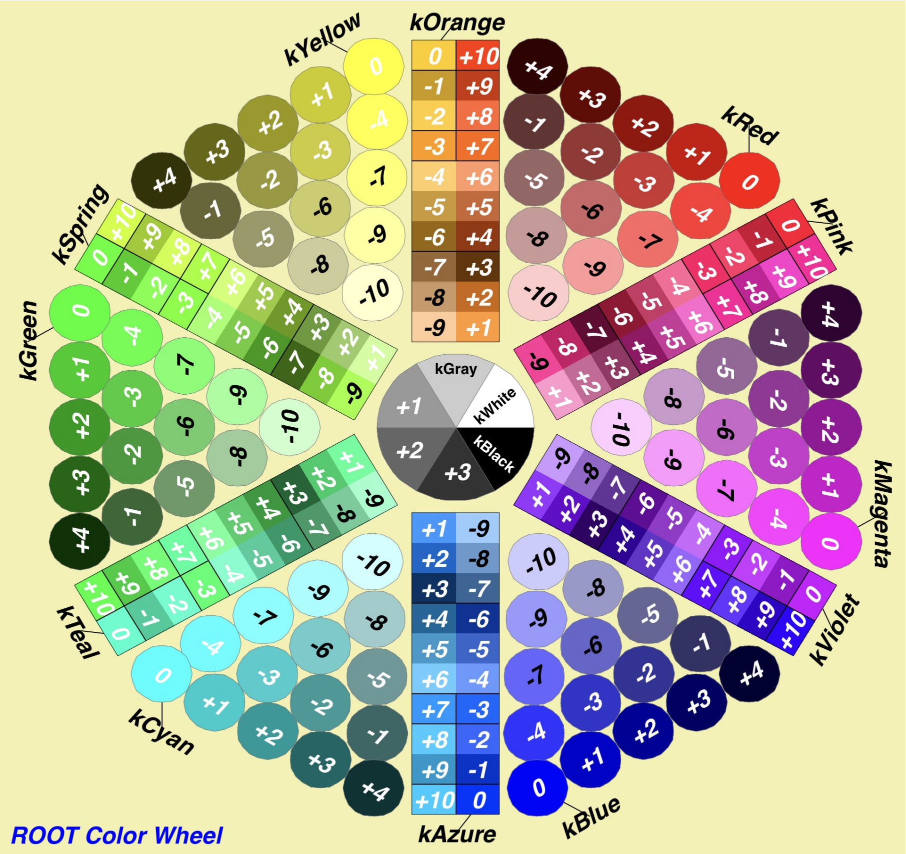
```
root [5] g.SetMarkerColor(kAzure)
root [6] g.SetLineColor(kRed - 2)
root [7] g.SetLineWidth(2)
root [8] g.SetLineStyle(3)
```



Question:
How do you find information on line styles?

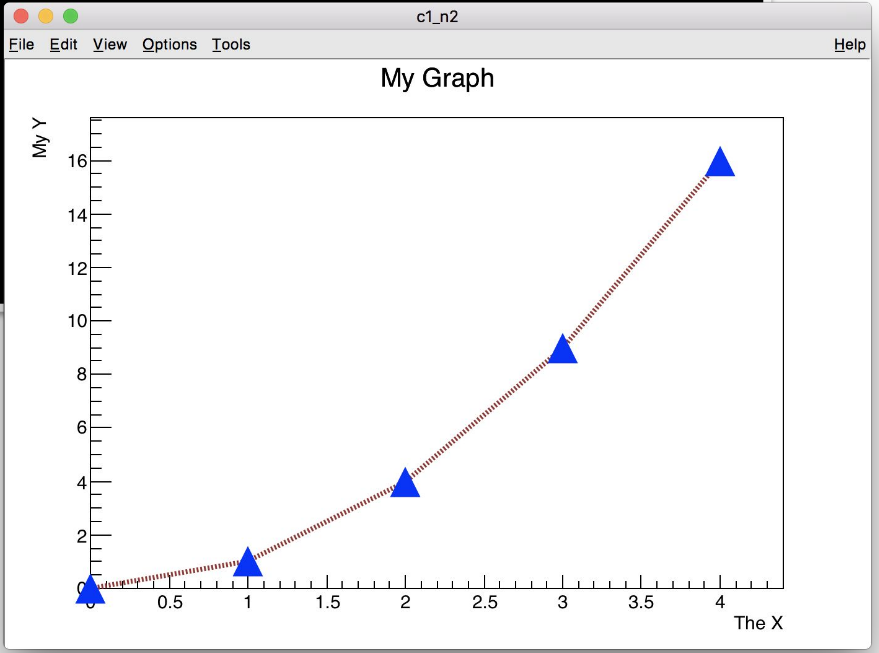
See [TAttLine documentation]

The Colors (TColorWheel)



My First Graph

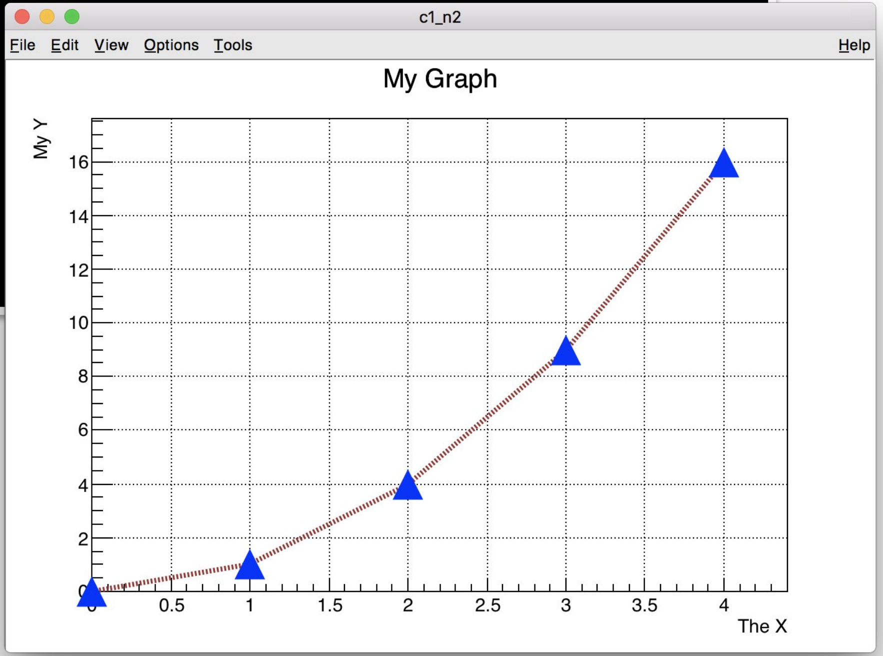
```
root [9] g.SetTitle("My Graph;The X;My Y")
```



Shortcut:
Directly set titles for x and y axis.

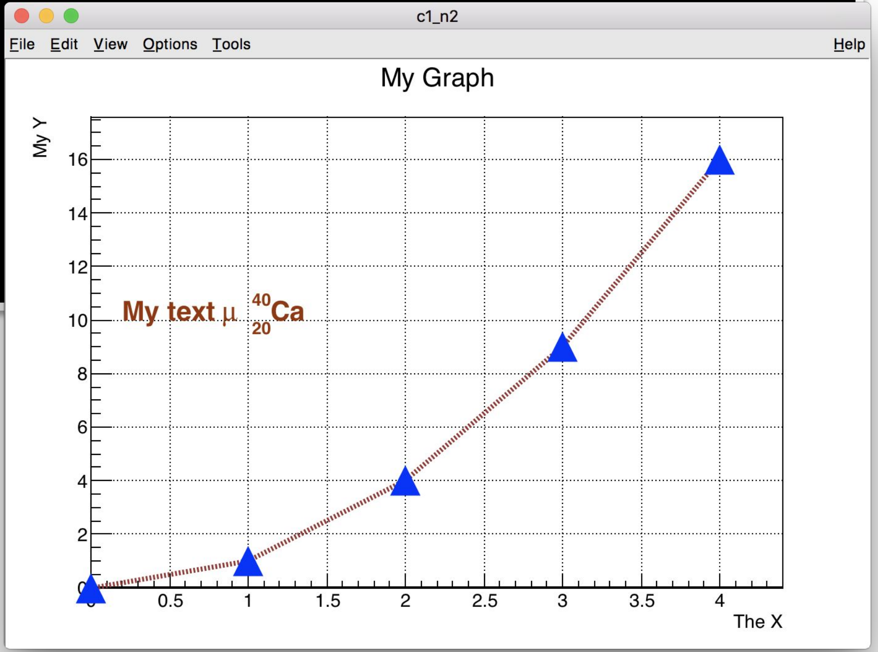
My First Graph

```
root [10] gPad->SetGrid()
```



My First Graph

```
root [10] auto txt = "#color[804]{My text #mu {}^{40}_{20}Ca}"
root [11] TLatex l(.2, 10, txt)
root [12] l.Draw()
```



My First Graph

```
root [13] gPad->SetLogy();
```