HEP Computing
Part III
ROOT
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Lectures 5-6

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Aims of this part of the course

The aim of this section is to give you a crash course in using ROOT. By the time you’ve worked through this you should be able to:

• set up the ROOT environment on your own machine
• start root and run a simple macro
• know how to use histograms, ntuples, files etc …
• know where to go for more information
• fit to histogram data
• compile a stand alone root application
• Write a script to process a macro on several root files – i.e. learn how to automate ‘chores’
• Learn about more root based tools – functions, binned fits in root and automatic code generation

This set of lectures has been tested for ROOT >= 5.27
Lecture 5

• Getting started with using ROOT.
  • ntuples
  • histograms
  • macros
• TFiles → saving data
• Using histograms and trees
• simple ROOT macros
• What is ROOT?
  
  C++ based, code on the web, actively developed by many people, don’t need to learn another syntax to use it (root macros are C++)
  
  ➔ flexibility brings complexity 😞
  ➔ manual is large (over 300 pages)
  ➔ some good web based courses available as well

• Useful resources:
  
  • User Guide etc:
    
    http://root.cern.ch/

  • HOW-TOs, Tutorials and class structure on web 😊
    (some tutorials listed in the references at end)
Some basic concepts

- **Histograms**
  - Plots of data as a function of 1, 2 or 3 variables

- **NTuples**
  - A more complicated data format
    - store information on an event or candidate basis
    - can cut on other variables in NTuple to do analysis on the fly
    - based on a tree-like data structure

- **Files**
  - The persistent data type
  - Persistent objects inherit from TObject
  - Can persist user defined objects if they inherit from TObject

- **macros**
  - Source file containing command to execute in the interpreter

- **GUIs**
  - Don’t always need to know how to do things on the command line!
1, 2 and 3D binned plots of the distribution of variables – good for visualising what analysis cuts do to data/complicated functions:

**types**

- TH1F
- TH1D
- TH2F
- TH2D
- TH3F
- TH3D

→ the F/D refers to the data type used either **Float_t** or **Double_t**

→ If you have a histogram called `myHist` and want to see what it looks like you Draw() it

```cpp
```

*The histogram object with variable name `myHist` the root prompt*

**Draw() member function is called to show the histogram**

*histogram shown as data points with background curves added on top of the histogram*
‘Flat File’ is jargon for a formatted text files containing columns of numbers corresponding to variables. e.g. a 3 column flat file would look something like:

```
5.285 0.02  5.43
5.273 -0.12 4.32
...
```

where you have the advantage of being able to read the numbers by eye as well as using them in code/scripts etc. (most people can’t read binary too well…)

You may see flat files knocking around from time to time.
NTuples

• data structure on an entry by entry basis (e.g. candidate or event)
  TTree/TChain – the same kind of thing – both are NTuples

You can
  • loop over the events one by one to analyse data
  • draw variables or combinations of variables
  • cut on variables as you draw them
  • fill histograms of anything that you can draw

• NTuples are a lot more flexible than histograms as you can optimize your analysis once you’ve made the ntuples → you don’t have to do this before making them
  → i.e. you make a few root files by running on all of the experimental data you need, using loose cuts and then work on this subset of data/variables.
The first part of the ROOT tutorial uses Monte Carlo data from a BaBar analysis to introduce the basics of using histograms, files and ntuples in root. The examples lead to you developing a scaled down version of what you would do in a cut and count analysis.

This tutorial concentrates on using ROOT with LINUX. There are pointers to differences between LINUX and mac, but the use of Windows is beyond the scope of these Lectures.
ROOT is a data analysis toolkit that has one main application

- **ROOT** the main program that you run

- You need to append `$ROOTSYS/bin` to your **PATH** in order for your shell to know where to find the command **root** (see the next page).

- You also need to modify **LD_LIBRARY_PATH** so that the shell can find the shared libraries it needs at run time (see the next page) in case you decide to start compiling your ROOT analysis code at a later date.

- ROOT (sort of) uses C++ syntax:
  - If you compile your code you need to be precise with C++ syntax.
  - If you interpret your code (using CINT, it is CLING in root6), then you don’t have to be as precise.
  - For the longer term, you should seriously consider compiling your code, however CINT is great for trying things out and learning!
  - There are a few limitations with CINT that you may encounter (e.g. templates)

N.B. mac users need to set the **DYLD_LIBRARY_PATH**
You (or your sys-admin) needs to have installed a version of root and to set the following environment variables:

- **ROOTVER** – the version number (not strictly necessary)
- **ROOTSYS** – The ROOT installation directory
- **LD_LIBRARY_PATH** – where the system looks for libraries
- You also need to append your path with the ROOT bin directory

If you use bash add the following to your `.bash_profile`.

```bash
export ROOTVER=5.27.00
# path to root install directory. This will depend on your sysadmin
goexport ROOTSYS=/users/bona/root/$ROOTVER
export PATH=$PATH:$ROOTSYS/bin:$MYPATHVAR
export LD_LIBRARY_PATH=$ROOTSYS/lib:$LD_LIBRARY_PATH
# on Mac OS X you’ll want to comment out the previous line and
# uncomment the following.
#export DYLD_LIBRARY_PATH=$ROOTSYS/lib:$DYLD_LIBRARY_PATH
```

- Run `$ROOTSYS/bin/thisroot.sh` to set-up a specific root version
- Log into a new terminal to see that your shell now knows about root.
Running ROOT

- **root**  
  *start a root session*

  -l  
  *suppress the ‘splash screen’*
  
  The splash screen is the window that pops up for a few seconds when you start root. By suppressing this you start root a little faster.

  -b  
  *run in batch mode [no graphics displayed]*
  
  This will speed things up a lot (especially if you are working from a remote machine).

  -q  
  *quit root when macro finished*
  
  `root -l -b -q myMacro.cc(“arguments”)`

- Can open a ROOT file when starting a session:

  `root myfile.root`
A few words on CINT/CLING

• Based on C++
• Is a C++ interpreter
• Can do things wrong sometimes (solution is to compile code)
  • you won’t get warnings when it does 😞
  • prime example is if you forget ‘;’ at the end of a line in a macro
    the whole line is just ignored!
• Some people say that ‘ROOT needs to be restarted all the time’
  • this is probably true if your code is not bug free!
  • if you are bug free then it is not a problem…
• There are differences between CINT and C++ some are:
  – Sloppy use of “–>” and “.”
    – these can be replaced with each other, however one gets
      warnings in later versions of root if using the wrong syntax
  – The “;” at the end of lines can be omitted in interactive use
    (not when running with macros!)
  – Can tab complete on an object in cint to see what it can do!
CINT/CLING commands

• CINT/CLING commands always start with a dot “." , e.g:

  .q  
  quit out of ROOT session

  .! <shellcommand>  execute a shell command, e.g.
  .! ls
  .! emacs myMacro.cc &

  .?  
  help; get list of CINT commands
ROOT Data Types

• Similar to C++:
  - Basic types: first letter is capitalised and have suffix “_t”:
    int → Int_t  float → Float_t  double → Double_t
  - Names of root classes start with “T” e.g.
    TDirectory, TFile, TTree, TH1F, TGraph, ...

• Some ROOT types (classes):
  - TH1F - 1D Histogram filled using floating precision data
  - TH1D - 1D Histogram filled using double precision data
  - TFile – a file containing persistent data
  - TDirectory – a directory (useful to keep a TFile tidy/organised)
  - TTree – can store per-event info in branches and leaves
  - TF1 – 1-dimensional function, TF2, ...
  - TString – a ROOT string object (better than a C/C++ string)
  - TObjString – a persistable root string
Why care about the difference between Float_t and float?

- The ROOT data types are used in order to make user code and ROOT code more platform independent.

- You probably don’t care or need to worry about the details of this

- However, in general you should try and use the ROOT defined types where possible
Tab Completion

Tab-completion of commands and filename calls can help in finding available commands, e.g.

```cpp
TH1F h1("h1", "title", 50, 0.0, 10.0);
   // define a histogram with 50 bins and an x axis range of 0.0-10.0
```

```cpp
h1.
   // lists all available functions of a TH1F object
```

```cpp
TH1::.\n   // list all available functions of a TH1 object
```

```cpp
TH1::.SetName(\n   // show the available function prototypes e.g.
```

```cpp
root [0] TH1::.SetName(\n   void SetName(const char* name) // *MENU*
```

so the syntax to change the name of this histogram is just:

```cpp
h1->SetName("myNewName")
```
Starting and exiting root

start up root by typing this at the shell prompt

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

quit root (remember this is CINT you are dealing with).

```
> root -l
root[0] TFile f1("somefile.root");
```

start up root by typing this at the shell prompt & suppress the splash screen

```
> root -l
root[0] TFile f1("somefile.root");
```

do something

```
root[n] .q
>
```
ROOT exercise 1: making sure you can use root

- log onto a machine with root installed on it
- download and untar the examples for part 3:
  these are unpacked in ./Lectures/macros/
- and cd into this dir.

- set up your root environment
- start a root session:
  root -l

e.g. copy the lines like those below from the example on page 11.

```bash
export ROOTVER=5.24.00
# path to root install directory. This will depend on your sysadmin
export ROOTSYS=/Users/bevan/root/$ROOTVER

export PATH=$PATH:$ROOTSYS/bin:$MYPATHVAR
export LD_LIBRARY_PATH=$ROOTSYS/lib:$LD_LIBRARY_PATH

# on Mac OS X you’ll want to comment out the previous line and
# uncomment the following.
#export DYLD_LIBRARY_PATH=$ROOTSYS/lib:$DYLD_LIBRARY_PATH

root -l -b -q hello.cc'("Yourname")'
```

• now you can play ....
root -l -b -q hello.cc'("Yourname")'
A root file is known as a TFile. That is the class name for the object. From your root prompt you can open the TFile data/signal.root using (from Lectures/macros)

```c
root[0] TFile f1("data/signal.root")
```

The content of the file can be seen by using the `ls()` member function:

```c
root[1] f1.ls()
TFile** signal.root
TFile* signal.root
KEY: TH1D cossphericity;1 cossphericity
KEY: TH1D photonlat;1 photonlat
KEY: TH1D pi0mass;1 pi0mass
.
.
KEY: TTree selectedtree;1 Final variables tree
```
Files

persistence = save data (histogram, ntuple, object) in a file

A root file is known as a **TFile**. That is the class name for the object. From your root prompt you can open the **TFile** data/signal.root using (from Lectures/macros)

```
root[0] TFile f1("data/signal.root")
```

The content of the file can be seen by using the `ls()` member function:

```
root[1] f1.ls()
TFile**         signal.root
TFile*          signal.root
    KEY: TH1D  cossphericity;1  cossphericity
    KEY: TH1D  photonlat;1      photonlat
    KEY: TH1D  pi0mass;1        pi0mass
    ...
    KEY: TTree  selectedtree;1  Final variables tree
```

- **object version number**
- **key object type**
- **key name**
- **comment**
- **a 1D histogram**
- **a TTree object (an NTuple)**
you can also **Print()** and **Dump()** information about the content of a file.

How do you get access to the persistent objects in a file? There are two ways:

```cpp
class TTree* const selectedtree = root[4];

TTree* mySignalTree = (TTree*)f1.Get("selectedtree");
```

The second way is better as it will ALWAYS work for multiple open files – you keep track of the pointers yourself and can do anything you want with them! If you are only using a single file then you can use the first way to access the stored objects when working interactively.

The default is a **TObject** *
ROOT exercise 2

1) Open the files found in the Lectures tarball:
   Lectures/macros/data/signal.root
   Lectures/macros/data/continuum.root
   and look at the content of the file (use **ls()** member function of **TFile**).

2) get pointers to the **TTrees** in each file – **Print()** the content of one of them [they are the same structure – so there is no point in looking at both of them 😊]

3) draw some of the variables:
   hint – you can cut on variables when you draw them
   ```
   mySignalTree->Draw("aVar");
   mySignalTree->Draw("aVar", "aCut", "same")
   ```
   e.g.
   ```
   mySignalTree->Draw("mes")
   mySignalTree->Draw("mes", "abs(de)<0.2", "same")
   ```
   • Do the same for a few histograms e.g.
     ```
     root [4] pi0mass
       (const class TH1D*)0x87a3df8
     root [5] pi0mass->Draw()
     ```
     can’t cut histograms

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Now you can

- set yourself up to use a given root version
- open a file in root
- access its content
- draw from TTrees and histograms (same works for TGraphs etc)

Q) Don’t like the grey background on the plots?
A) root [4] gROOT->SetStyle("Plain") will solve that problem for you.

The next part of the course is to write a macro that loops over the events in a TTree and makes some cuts – filling histograms. These histograms are then written out to a new file. Then you can compile the code stand-alone and see it run faster.

For now however I’ll go into more detail on histograms and TTrees as we build towards this goal.
Histories

Declare with:

```cpp
TH1F h1(arguments ...)
```

- **Make your first 1D histogram:**
  ```cpp
  TH1F h1("h_name", "h_title", 10, 0.0, 10.0);
  h_name = key name of histo
  h_title = name which appears on plotted histogram
  ```

- **Now draw the (currently empty) histo:**
  ```cpp
  h1.Draw();
  ```

- **Fill with a few entries:**
  ```cpp
  h1.Fill(1.);
  h1.Fill(3,10.7);
  ```

- **Try drawing the histogram when you have a few entries**
  ```cpp
  h1.Draw(); //do this occasionally to update the histogram
  ```
Some useful commands to play with now that you’ve got a histogram

```cpp
h1.SetFillColor(Color_t color = 1)  // Change the fill colour.
h1.SetFillStyle(Style_t styl = 0)  // Change the fill style.
h1.SetLineColor(Color_t color = 1)  // Change the line colour.
h1.SetLineStyle(Style_t styl = 0)  // Change the line style.
h1.SetLineWidth(Width_t width = 1)  // Change the line width.
```

Line colours and styles are described in the 'Graphical Objects Attributes' section of the ROOT user guide.

kRed  
kOrange  
kYellow  
kSpring  
kGreen  
kTeal  
kCyan  
kAzure  
kBlue  
kViolet  
kMagenta  
kBlack  
kPink

Make sure you use colours wisely! There is nothing more annoying than seeing a talk projected onto a screen with half a dozen invisible lines!

Try and stick to 'safe' colors like blue, red and black.

Can define new colours using the TColor class.
Some useful commands to play with now that you’ve got a histogram

```c
h1.SetFillColor(Color_t color = 1)  // Change the fill colour.
h1.SetFillStyle(Style_t styl = 0)  // Change the fill style.
h1.SetLineColor(Color_t color = 1)  // Change the line colour.
h1.SetLineStyle(Style_t styl = 0)  // Change the line style.
h1.SetLineWidth(Width_t width = 1)  // Change the line width.
```

Line colours and styles are described in the 'Graphical Objects Attributes' section of the ROOT user guide.

![Available fill styles shown left](image)

Remember to give axis labels a sensible title:

```c
h1.SetXTitle("This is the x-axis")
h1.SetYTitle("This is this y-axis")
```

**always label your axes!**
The default line style is $\text{kSolid}$. There are times when you will want to change this to another value (either by integer or enum):

- $\text{kDashed}$
- $\text{kDotted}$
- $\text{kDashDotted}$

Sometimes it can be useful to mark points on a histogram using a TMarker. There are various marker styles:

Which can be used as follows:

```cpp
TMarker myMark(xCoord, yCoord, iStyle)
myMark.SetMarkerColor(kRed)
myMark.Draw()
```

where xCoord and yCoord are the coordinates to plot the marker at (in terms of the histogram or graph), and iStyle is one of the marker styles above.
It is also possible to change the range of the x-axis that you want to plot a histogram for using

\[ h1.SetAxisRange(xMin, xMax) \]

where \( xMin \) and \( xMax \) should be within the range defined in the constructor.

**Why don't I see the changes I made to a histogram?**
If you modify the settings of a histogram (or marker), you will need to redraw the object in order for it to be updated on the TCanvas.

**Overlaying more than one histogram on a plot**
More than one histogram can be drawn on top of each other using \( h1.Draw("same") \). This only makes sense if the axes have matching ranges.

**Errors on a histogram:**
Bin entries on a histogram are an accumulation of events occurring with a probability according to a Poisson distribution.
If you use \( h1.Draw("e") \), ROOT will draw error bars for you.
2D Histogram

TH2F h2("h_name", "h_title", 10, 0.0, 10.0, 20, -10.0, 20.0);

• 2D histograms behave the same as 1D histograms

• have some interesting Draw() options
  *surf* - draw a surface
  *surf1* - draw a surface with colour contours
  *cont* - draw a contour plot
  *contz0* - draw a contour plot with the y axis scale shown
  *lego* - draw a 2D histogram
  *box* - draw boxes (default is to spread points out according to the defined bins)
  *text* - draw 2D grid of number of entries per bin.

• These draw options also work for trees
myHist.Draw()

myHist.Draw("surf")

myHist.Draw("contz0")

myHist.Draw("box")
myHist.Draw()

myHist.Draw("lego")

myHist.Draw("surf1")

myHist.Draw("text")
Making histograms from a TTree

• When you draw a variable from a TTree you can fill a histogram

```c
myTree.Draw("mes>>tmphist");
tmphist.Draw("e");
```

Now root knows you have a histogram of name `tmphist`

`tmphist` is a histogram made to have the content corresponding to that of the tree

If you have already defined the histogram `tmphist`, then ROOT will fill this for you from the tree. If you have not defined `tmphist` ROOT will make a guess as to the axis ranges, and will create a 100 bin histogram for you.
Making histograms from a Ttree (II)

myTree.Draw("mes>>tmphist");
myTree1.Draw("mes>>+tmphist");
myTree2.Draw("mes>>+tmphist");

tmphist.Draw("e");

>>+ means add to existing histogram

By default you get a histogram with 100 bins. If you want to change this you’ll have to specify a histogram yourself; e.g.:

    TH1F tmphist("tmphist", "", 25, 5.2, 5.3);
    myTree.Draw("mes>>tmphist");
Macros

• Lots of commands you’ll want to repeat often just like scripts in terms of shell programming or source files in terms of programming.
  – save them in a “macro” file (same concept as a PAW kumac)
  – just a bunch of commands in file, enclosed in {...}

• The following is an example of an un-named macro:

  ```
  {
    TFile f("data/signal.root");
    f.ls();
    TCanvas c1;
    pi0mass.Draw();
    c1.Print("pi0mass.eps");
  }
  ```

• You save macros as a C file; e.g. `myMacro.cc`
  (actually the extension that you use can be anything).

• To execute an un-named macro:
  ```
  root[0] .x myMacro.cc
  ```
  On doing this ROOT will run all the commands in `myMacro.cc`. 
The following is an example of a named macro:

```cpp
void myMacro(void)
{
    cout << "Hello World!" << endl;
}
```

If the macro name is the same as a function then you can run the macro from the ROOT prompt with

```bash
root[0] .x myMacro.cc
```

or from the command line with

```bash
> root -l -b -q myMacro.cc
```

named macros like this are `#include`able in other files.
You can pass an argument to a named macro from the command line or ROOT.

Try running the following example:

```
root hello.cc'("Your name")'
```
• Combine named and un-named macros to build up an analysis.

• Macros can call and use other macros.

• Syntax to load a macro from a file:
  ```
gROOT->LoadMacro("myFile.cc");
  ```
  formal version of the CINT command line `.L myFile.cc`

• If you will use the function frequently, better to have named macro or define the function in a header file you can `#include` from your macros.

• Scope works the same as in C++, anything defined in a macro or function exists only inside that macro or function.

• Complicated analyses should be compiled using gcc or another C++ compiler (to help you debug it and speed up the analysis).
Lecture 6

• More on TFiles – making a new file
• Reading data from a tree on an entry by entry basis
• Makefiles
• The ‘main()’ function
• Compiling a stand-alone executable
• Using scripts to run a ROOT analysis
TFiles

You’ve already met **TFiles** – a bit more on how to use them
- Files can contain directories, histograms and trees (ntuples) etc.
- These are ‘persistent’ objects
- In root you make an object persistent by inheriting from **TObject**

A few file commands/constructors that you’ve already met:
• Open an existing file (read only)
  
  ```cpp
  TFile myfile("myfile.root");
  ```

• Open a file to replace it
  
  ```cpp
  TFile myfile("myfile.root", "RECREATE");
  ```
  or append to it:
  
  ```cpp
  TFile myfile("myfile.root", "UPDATE");
  ```

• Some useful member functions include
  
  ```cpp
  TFile::GetName();
  TFile::GetTitle();
  TObject * TFile::Get(const char * )
  ```
Tfiles (II)

- Open an existing file (read only)
  ```
  TFile myfile("myfile.root");
  ```

- Open a file to replace it
  ```
  TFile myfile("myfile.root", "RECREATE");
  ```
  or append to it:
  ```
  TFile myfile("myfile.root", "UPDATE");
  ```

- Some useful member functions include
  ```
  TFile::GetName();
  TFile::GetTitle();
  TObject * TFile::Get(const char * the object key name)
  ```

  ```
  TObject * - you have to “cast up” the returned object to the persistent type to be able to use it properly. This is just what you did earlier with:
  ```
  ```
  TTree * mySignalTree =
  (TTree*)myfile.Get("selectedtree")
  ```
Using TFile::Get()

Open the file `signal.root` (This is $B^0 \rightarrow \pi^0\pi^0$ Monte Carlo simulated data)

```
root[0] TFile myfile("data/signal.root")
root[1] myfile.ls()
TFile** signal.root
TFile* signal.root
  KEY: TH1D cossphericity;1 cossphericity
  KEY: TH1D photonlat;1 photonlat
  KEY: TH1D pi0mass;1 pi0mass
  .
  .
  .
  KEY: TTree selectedtree;1 Final variables tree
```

```
root[2] TH1D * cossph = (TH1D*)signal.Get("cossphericity");
root[3] TH1D * lat = (TH1D*)signal.Get("photonlat");
root[4] TH1D * mpi0 = (TH1D*)signal.Get("pi0mass");
```

```
root[5] mpi0->Draw();
root[6] lat->Draw();
root[7] cossph->Draw();
```

"Get" the 3 histos in memory

Try looking at the histograms

The key type is the root object type 😊
What if you want to make a new file?

TFile newfile("myNewFile.root", "RECREATE", "comment");

//make some histograms
TH1F aHist("aHist", "some variable", 10, 0.0, 10.0);
TH2D a2DHist("a2DHist", "x vs y", 10, 0.0, 1.0, 100, -4.0, 4.0);

// make a new tree containing two scalar variables and an array
Float_t x,y;
Int_t n[10];
TTree mytree("mytree", "title");
TBranch * b_x = mytree.Branch("x", &x, "x/F");
TBranch * b_y = mytree.Branch("y", &y, "y/F");
TBranch * b_z = mytree.Branch("n", n, "n[10]/I");

// do stuff
newfile.Write();
newfile.Close();

You have to `Write()` a file to save what you have done. It will get closed when it goes out of scope (or is deleted).
Alternatively...

// make some histograms
TH1F aHist("aHist", "some variable", 10, 0.0, 10.0);
TH2D a2DHist("a2DHist", "x vs y", 10, 0.0, 1.0, 100, -4.0, 4.0);

// make a new tree containing two scalar variables and an array
Float_t x,y;
Int_t n[10];
TTreemytree("tree", "title");
TBranch * b_x = mytree.Branch("x", &x, "x/F");
TBranch * b_y = mytree.Branch("y", &y, "y/F");
TBranch * b_z = mytree.Branch("n", n, "n[10]/F");

// do stuff (e.g. your selection code)

// persist all objects to a file at the end of the macro
TFile newfile("myNewFile.root", "RECREATE", "comment");
aHist.Write();
a2DHist.Write();
mytree.Write();
newfile.Write();
newfile.Close();

you can also Write() objects to the file to save what you have done at the end of the macro, just before things go out of scope
Trees

• **ROOT trees (TTree)**
  – Trees can contain different types of data (e.g. Int_t, Bool_t, Float_t, Double_t). The trees have branches (subdirectories).
  – Trees also have leaves that represent variables and contain data.
  – Trees are optimized to enable fast access to data, and minimize disk space usage.

• Trees (with leaves but not branches) can be thought of like tables:
  – rows can represent individual events
  – columns (leaves) represent different event quantities

• Some useful function calls for a TTree:
  – To view the content (variables) in a tree: myTree->Print()
  – To inspect event iEvt (print out values of leaves): myTree->Show(iEvt)
  – To draw a distribution of a leaf myTree->Draw("variable")
  – To draw a 2D distribution of x vs. y myTree->Draw("x:y")
  – To draw x while cutting on y myTree->Draw("x", "y>5")
TTree * mytree = (TTree*)myfile.Get("selectedtree");

Float_t mes, de, fisher, imass[3];

// set the tree up to fill local variables
mytree->SetBranchAddress("mes", &mes);
mytree->SetBranchAddress("de", &de);
mytree->SetBranchAddress("newfish", &fisher);
mytree->SetBranchAddress("imass", imass);

// loop over the candidates in the TTree
for(int iEvt = 0; iEvt < mytree->GetEntries(); iEvt++)
{
    mytree->GetEntry(iEvt); // load the candidate #iEvt
    cout << "candidate iEvt = " << iEvt << "\t mes = " << mes << endl;
}

Set the Branch to fill local variable - you can update the value to that variable for any iEvt in the tree

The number of events or candidates in a tree (there is one per call to the tree->Fill() function).

Load the entry iEvt into the local variables mes, de, fisher & imass
Building a tree from scratch

// declare variables to use in the tree
Float_t x, y;
Int_t n[10];

// make the tree object
TTree mytree("tree", "title");

// set up the tree structure
TBranch * b_x = mytree.Branch("x", &x, "the variable x/F");
TBranch * b_y = mytree.Branch("y", &y, "the variable y/F");
TBranch * b_n = mytree.Branch("n", n, "n[10]/I");

for(Int_t i = 0; i < 100; i++)
{
    //do stuff to fill variables with a value
    [...]  
    mytree.Fill();
}

An array used in this way is a pointer so you don’t need the &
fill the tree with another entry you have to set the values of x, y and i before doing this
1) Write a macro that takes the name of a file as an input, opens this and get the tree out of it to loop over (e.g. signal.root etc.)

2) Extend this macro so that you also make a second tree
   - this should contain the variables:
     mes
de
newfish
   - do this while cutting on mes and de such that:
     \[5.2 < \text{mes} < 5.29\]
     \[-0.4 < \text{de} < 0.4\]
   - loop over the events in the original tree writing those out that pass the cuts listed to the new tree and save to a new file.

There is an example solution saved as \texttt{myRootStuff.cc}
Some more advanced ROOT usage

• The last exercise made you write the essence of a simple analysis in root.

• As your analysis gets more complicated you’ll probably introduce a few bugs and write some code that may well take a long time to run.

• When you start doing this – it is worth thinking about compiling your code to make sure it is robust and at the same time speed up its execution.

• use Makefiles to compile a stand alone application
  – faster run time execution
  – better error checking at compile time
  – get to debug output when things core dump
  – introduce you to (simple) Makefiles
The Makefile

use `root-config` to define libraries and include paths for you

```
LIBS=`root-config --libs`
CFLAGS=`root-config --cflags`
CC=g++

# set compiler options:
#   -g  = debugging
#   -O# = optimisation
COPT=-g

default:
   $(CC) $(COPT) main.cc -o main $(LIBS) $(CFLAGS)

clean:
   rm main
```

The Content of a Makefile

- **targets** – e.g. `gmake` – compile the default target
- `gmake clean` – run the clean target

set compile options

file(s) to compile

output binary name

this is a [tab]
you will need to #include some files to make sure that the stand alone application finds the necessary declarations …. 

Some useful files are:
- TNamed.h knows about basic types such as Float_t
- TString.h
- TFile.h
- TTree.h
- TChain.h
- TH1F.h
- etc.

If you use an object in root then you will need to #include the corresponding header file e.g.

```
#include "TNamed.h"
#include "TString.h"
```

etc.

A comprehensive list of classes can be found at:  
1) Write a file containing a main function – for example – put the following in a file called main.cc:

```cpp
#include <iostream>
#include "myRootStuff.cc"
using namespace std;

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

int main(int argc, char * argv[])
{
    // decode command line arguments
    char inputfile[256] = "";
    for(int iArg = 1; iArg < argc; iArg++)
    {
        if(!strcasecmp(argv[iArg],"-file")) strcpy( inputfile, argv[++iArg] );
    }

    // call root stuff in include file
    myRootStuff(inputfile);

    return 0;
}
```

include your root macro

prototype for main

main function that calls the macro entry point
2) Now you can \texttt{gmake} (or \texttt{make}), fix any errors and run the application – the application will be called \texttt{main} as specified after the \texttt{-o} in your Makefile.

\textbf{ERRORS} \rightarrow \text{will stop you being able to compile the program}

\textbf{Warnings} \rightarrow \text{you might have a problem with the way you have written it is good practice to make sure you don’t have any warnings}

3) run the application you have just compiled:

\texttt{./main \textendash;file signal.root}

\rightarrow If you got stuck with this at any point there are examples of Makefile, main.cc and myRootStuff.cc in Lectures/macros so you can take a look at these and play about with them…

- \textbf{entry point}:
  this is the thing that is called when the system runs a program. For a C/C++ program this is a function called main. For a ROOT macro, it is the function with the same name as the macro file.
Using scripts to run root

Now that you have a working executable you can run it using:

```bash
./main –file data/signal.root
```

An alternative way to do this is to pass the argument to the macro when you start root and remember to quit root when done:

```bash
root -l -b -q myRootStuff.cc'("root file name")'
```

You have two files to convert in this way – so you can run the program on one file and rename this. Then run the program on the second file. Imagine that you had 50 such files to do this to (i.e. many different possible backgrounds) … are you still going to do this by hand?

**Exercise:**

1) write a script to loop over the root files in `data/` and run your macro or binary program on these files.

→ *make sure that you’re happy with doing this kind of thing as it will be useful*

```
usingScriptsToRunRoot.csh
```
More fun with ROOT
The following is additional material that will not be covered in Lectures.

The next section builds your knowledge of what you can do in root with more emphasis on presentation than the previous slides.

There is less formal structure in what follows
TCanvas and TPad

Canvas: a graphics window where histograms are displayed

• It is very easy to edit pictures on the canvas by clicking and dragging objects and right-clicking to get various menus.

• A ROOT canvas is a TCanvas object.

• the default canvas, c1, is created on first call to Draw(). This is equivalent to

\[
\text{TCanvas} \ *c1=\text{new TCanvas} ("c1","",800,600);
\]

• Update canvas (if you make a change): canvas->Update();

• Tidy up canvas: canvas->Clear();

• Initially, the canvas has one pad which covers whole canvas → can use Divide

See FNAL tutorials and the ROOT User Guide for more on the use of canvases, pads and the ROOT GUI
• You can split canvas into several TPad(s), with
  canvas->Divide(2,2);
canvas->Divide(nX, nY);

• You can plot different histograms on different pads
  • To change the pad you are working with use (where iPad ≤nX×nY)
canvas->cd(iPad)

• Save the contents of the canvas to a file
  canvas->Write()

• Can save as ps, eps or gif using SaveAs() and Print()
canvas->SaveAs("file.ps")
canvas->SaveAs("file.eps")
canvas->SaveAs("file.gif")
canvas->Print("file.ps")
etc..

• Also can make TPad(s) by defining the co-ordinates by hand.

Can’t run in batch mode
TFile f("data/signal.root")
TTree * mytree =
  (TTree*)f.Get("selectedtree")

TCanvas c1("c1")
c1.Divide(2,2);

c1.cd(1)
mytree->Draw("fde:fmec", "fmec>5.2")
c1.cd(2)
mytree->Draw("fde:fmec", "fmec>5.2", "surf")
c1.cd(3)
mytree->Draw("fde:fmec", "fmec>5.2", "contz0")
c1.cd(4)
mytree->Draw("fde:fmec", "fmec>5.2", "box")
To set up the stats box

```c
//default setting
gStyle->SetOptStat();

//no stats box
h1->Draw();
gStyle->SetOptStat(0);

//update canvas
h1->Draw();
gStyle->SetOptStat(1111111);

//turn all options on
h1->Draw();
gStyle->SetOptStat(1111111);

//name & #events only
h1->Draw();
gStyle->SetOptStat(11);
```

**Statistics Box**

- Default placing – top right
- Various statistics can be displayed,
  - histogram name, mean, rms, number of entries, over- and under-flows [i.e. entries out of range]
Legends

• **TLegend** - the key to the lines/histograms on a plot

• E.g. for a two-line histo (**h1** and **h2**):

  ```cpp
  TLegend myLegend(0.1, 0.2, 0.5, 0.5, "myLegend")
  myLegend.SetTextSize(0.04);
  myLegend.AddEntry(&h2, "after cuts", "l");
  myLegend.AddEntry(&h1, "before cuts", "l");
  myLegend.Draw();
  ```

  “l” (lowercase 'L') instructs ROOT to put a line in the legend.
• Use text box (TPaveText) write on plots, e.g.:

```cpp
TPaveText *myText = new TPaveText(0.2, 0.7, 0.4, 0.85, "NDC");
    //NDC sets coords relative to pad
myText->SetTextSize(0.04);
myText->SetFillColor(0);        //white background
myText->SetTextAlign(12);
myTextEntry = myText->AddText("Here’s some text.");
myText->Draw();
```

• Greek fonts and special characters:

```cpp
h1->SetYTitle("B^{0} \bar{B^{0}}");   //must have brackets
h1->SetTitle("\tau^{+}\tau^{-}");     // to get super/subscript
```

The special characters that root knows are defined in the TLatex class. These are very similar to the use of latex maths commands but with ‘\’ → ‘#’; e.g.

<table>
<thead>
<tr>
<th>latex</th>
<th>root</th>
</tr>
</thead>
<tbody>
<tr>
<td>\tau</td>
<td>#tau</td>
</tr>
<tr>
<td>\alpha</td>
<td>#alpha</td>
</tr>
</tbody>
</table>

not everything is available in TLatex
Symbols known to TLaTeX.
N.B. these are all proceeded by a '#' symbol.

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

\[ \#club, \#diamond, \#heart, \#spade, \#Jgotic, \#Rgotic, \#LT, \#GT, \#propto, \#notsubset, \#subset, \#subseteqq, \#supseteqq, \#supseteq, \#subseteqq, \#cup, \#cap, \#ocopyright, \#copyright, \#doublequote, \#angle, \#uparrow, \#downarrow, \#rightarrow, \#leftarrow, \#topbar, \#lbar, \#bottombar, \#rightarrow, \#uparrow, \#otimes, \#oplus, \#surd, \#int \]
Fitting 1D Functions

- Fitting in ROOT based on Minuit (ROOT class: TMinuit)
- ROOT has 4 predefined fit functions, e.g.
  - gaus: Gaussian function \( f(x) = p_0 \exp\left\{-\frac{1}{2}\left[(x-p_1)/p_2\right]^2\right\} \)
  - landau: Landau function (see the literature for a full dfn).
  - expo: exponential function \( f(x) = p_0 \exp(p_1 \times x) \)
  - polyN: polynomial of order N, N=0, 1, 2, ... 9.

- Fitting a histogram with pre-defined functions, e.g.
  \[ h1->Fit("gaus"); \]

- User-defined: 1-D function (TF1) with parameters:
  \[ \text{TF1 } *\text{myFn} = \]
  \[ \text{new } \text{TF1("myfn","[0]*\sin(x) + [1]*\exp(-[2]*x)",0,2);} \]

- Set param names (optional) and start values (must do):
  \[ \text{myFn->SetParName(0,"paramA");} \]
  \[ \text{myFn->SetParameter(0,0.75);} //\text{start value for param [0]} \]

- Fit a histogram:
  \[ h1->Fit("myfn"); \]
• Fitting with user-defined functions often requires solving a more complicated problem. Save the following as a macro called myfunc.cc

```cpp
double myfunc(double *x, double *par)
{
    double arg=0;
    if (par[2]!=0) arg=(x[0]-par[1])/par[2];
    return par[0]*TMath::Exp(-0.5*arg*arg);
}
```

• **double *x** is a pointer to an array of variables
  – it should match the dimension of your histogram
• **double *par** is a pointer to an array of parameters
  – it holds the current values of the fit parameters
• now try and fit a histogram h1 with your function

```cpp
.L myfunc.cc
TF1 *f1=new TF1("f1",myfunc,-1,1,3);
f1->SetParameters(10, h1->GetMean(), h1->GetRMS());
h1->Fit("f1");
```
Fitting III – The Fit Panel

- Open a fit panel for your histogram with:
  ```cpp
gmyHistogram->FitPanel();
```  

Specify the fitting function you want to use in the text box (has to be one known to ROOT).

Can switch between a $\chi^2$ fit or a likelihood fit.

Can use the slide bar at the bottom to restrict the fit range to a sub-sample of your data.

To run or re-run a fit press the 'Fit' button.
• If you have a complicated maximum-likelihood fit that you want to perform – don’t do this by writing your own fit functions from scratch in ROOT.

• There is a package in ROOT called RooFit. This is a fitting package that is written by members of the HEP community to do complicated analyses (started on BaBar).

• There are tutorials on the web and the code is also available at the source forge: http://roofit.sourceforge.net/

• I would recommend that you think about using this if you have to do any unbinned maximum likelihood fit analysis as once you get started RooFit is a very powerful and flexible tool for easily building very complicated PDFs to fit to.
• The **TBrowser** is the ROOT graphical interface

• It allows quick inspection of files, histograms and trees

• Make one with:
  ```
  TBrowser tb;
  ```

• More formally:
  ```
  TBrowser *tb = new TBrowser;
  ```

• Full details on how to manipulate the browse are in the ROOT user guide.
Using the TBrowser

• Start in ROOT with:
  \[ \text{TBrowser tb;} \]
• Any files already opened will be in the \textit{ROOT files} directory
• Directory ROOT session started in will be shown too
• Otherwise click around your directories to find your files
• Click to go into chosen directory
• Double-click on any ROOT files you want to look at (you won’t see an obvious response)
• Now go into the \textit{ROOT files} directory
• Selected files now there
• Can click around files, directories, trees
• Can view histograms and leaves
Automatic code generation

You can simplify analysis of large ntuples by using built in automatic code generation methods available in ROOT. You have already learnt what you have to do to analyse NTuples in the examples – so you are now in a position to cheat to get the job done faster 😊

```cpp
mytree->MakeCode()  // obsolete -> use MakeClass or MakeSelector instead
mytree->MakeClass()  // make a class with a loop() member function to run over the tree
mytree->MakeSelector()  // similar
```

Try these out to see what is auto generated. Toy should have a nameless macro in the first case and classes for the latter two. Usually I start from MakeCode(), but on occasion use MakeClass().
Summary

• You’ve now reviewed some of the basics UNIX, shell scripting & perl so that you can get these to do work for you – you’ll probably need more practice
• had a crash course in root … and done some analysis
• seen histograms and ntuples close up.
• written a simple Makefile to compile your root code to make it faster
• used a script to run a job – automating work for you

The next step with this is to practice what you’ve learnt – this way you’ll better recognise when to do certain things to make your life easier than it currently is

If you find yourself wasting time doing the same thing over and over again there is something out there to learn so that you can save time and get back to the real job at hand …. Physics!
Where to Get More Information
ROOT

• The ROOT homepage:
  http://root.cern.ch/
  – examples, HOWTOs, tutorials, class information, ROOT source code
  – RootTalk mailing list – high traffic, great search facility

• Fermilab’s three-day ROOT course
  http://patwww.fnal.gov/root

• SLAC’s root web pages:

• Other students/post-docs in the group

• Email me: m.bona@qmul.ac.uk