ROOT manual for GATE users

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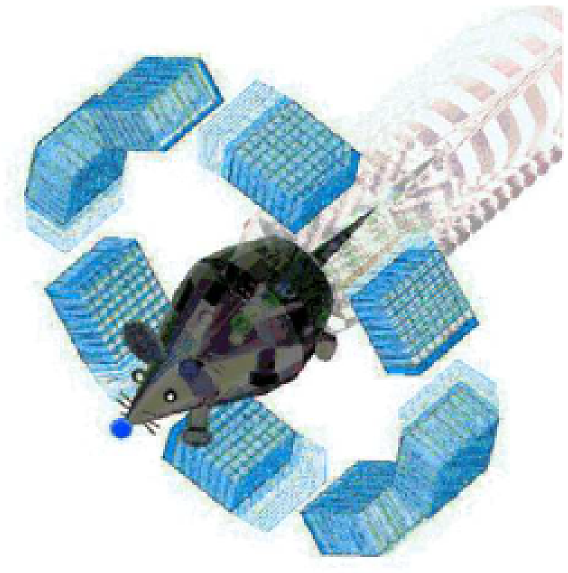

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Contents

Abstract

This manual is for GATE users who want to become familiar with ROOT output files. This documents contains simple actions with ROOT files. Though, despite their apparent simplicity, they are very useful and sometimes not easy to figure out. In some sense it is the manual of "Getting started" with ROOT. Some of the used files and scripts you can find on my github, link is here. Please, do not hesitate to contact the author at kochebina@gmail.com if you have any questions and comments. And of course, I strongly invite you to visit and use the ROOT web site, https://root.cern.ch/. This manual is a brief introduction. Hopefully, it will help you in your first steps and save you some time.

Have fun!

The author would like to thank Benoit VIAUD who taught me almost everything that you will find in this manual.

1 Obtain your ROOT file

The standard way to get ROOT output is to add in your GATE macro:

```
/gate/output/root/enable
/gate/output/root/setFileName        YourOutputFile
```

This command creates a file `YourOutputFile.root`, which contains usually several ROOT TTree objects, like Hits, Singles, Coincidences. TTree is a ROOT object consisting of a list of independent branches (TBranch). Each of them corresponds to saved variables from obtained in GATE simulation. It can be energies, hit positions, process IDs etc. for each generated event.

One can choose the standard TTree with commands:

```
/gate/output/root/setRootHitFlag        1
/gate/output/root/setRootSinglesFlag      1
```

In this case the .root file will contain default trees of Singles and Hits.

It is possible to add a TTree, for example, with an energy selection. To do so one should add in digitizer something like:

```
/gate/digitizer/name peak171
/gate/digitizer/insert singleChain
/gate/digitizer/peak171/setInputName Singles
/gate/digitizer/peak171/insert thresholder
/gate/digitizer/peak171/thresholder/setThreshold 153.9 keV
/gate/digitizer/peak171/insert upholder
/gate/digitizer/peak171/upholder/setUphold 188.1 keV
```

This will add to the .root file a TTree with a name peak171 which will contain Singles events with energies [153.9,188.1] keV. The more details could be found on GATE wiki page.

2 Painless ROOT file opening

The simplest way to open your ROOT file is to type in terminal:

```
> root -l YourOutputFile.root
```

Option `-l` removes the ROOT start image.

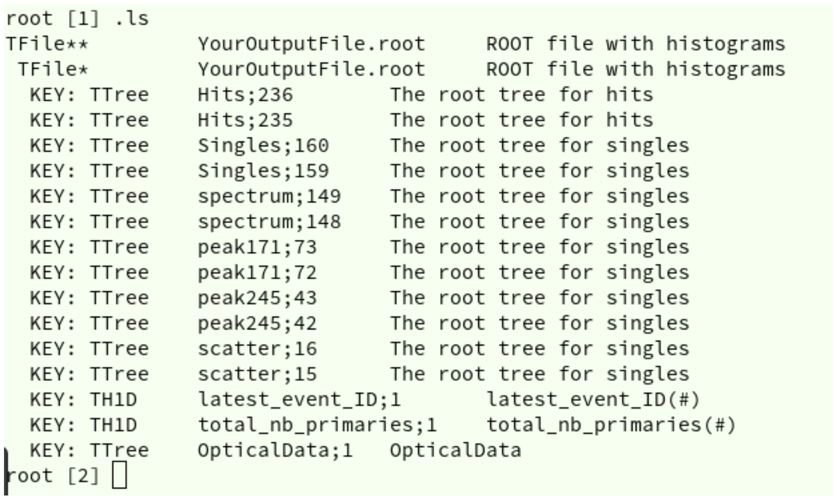
There are two ways to check the content of your file:

1. use a `TBrowser`, which is not very powerful and gives an access to visualize the structure of your ROOT file but is very limited for selection application or histogram superposition

2. **Recommend way** is to use command in terminal:

   ```
   root[0] .ls
   ```

This command will display the list of all ROOT objects contained in your file or that you created in the current ROOT session (see Figure 1). The first column corresponds to the type of objects (TFile, TTree, root histogram TH1D, etc). The second is the name followed by the third column which is a short description of the element. Sometimes the TTrees are repeated twice, this should not bother you.



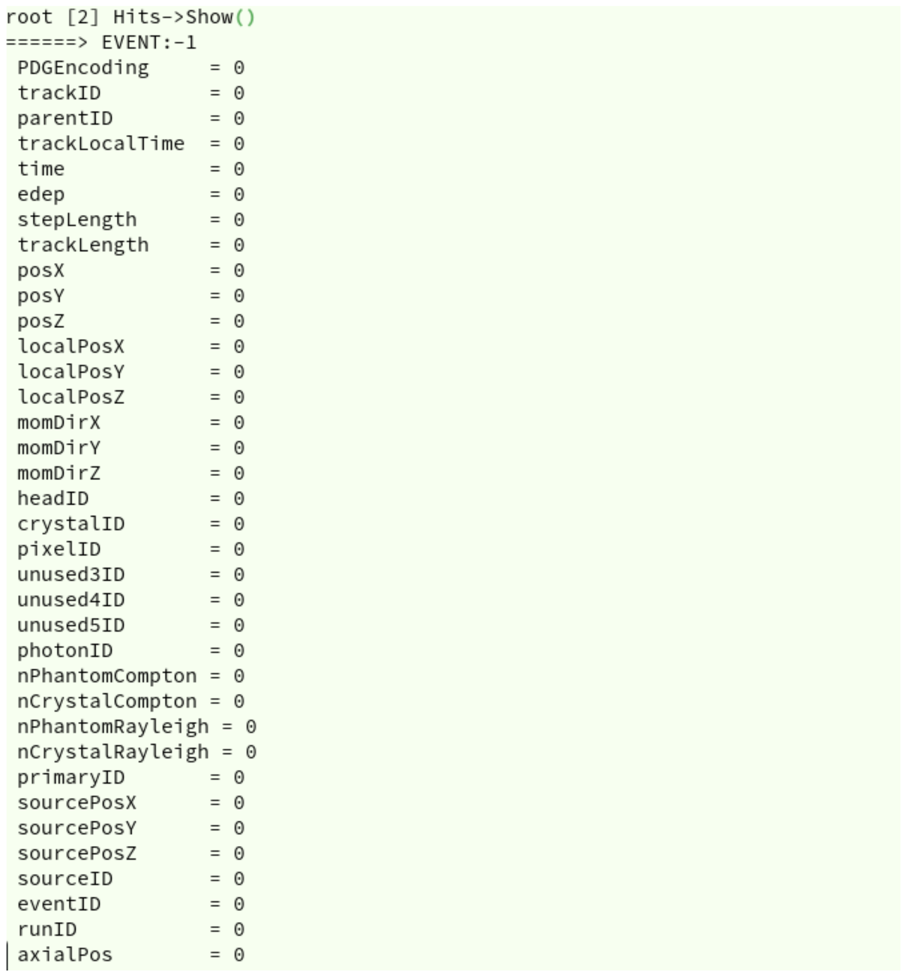
```
root [1] .ls
TFile**         YourOutputFile.root     ROOT file with histograms
 TFile*         YourOutputFile.root     ROOT file with histograms
  KEY: TTree    Hits;236        The root tree for hits
  KEY: TTree    Hits;235        The root tree for hits
  KEY: TTree    Singles;160     The root tree for singles
  KEY: TTree    Singles;159     The root tree for singles
  KEY: TTree    spectrum;149    The root tree for singles
  KEY: TTree    spectrum;148    The root tree for singles
  KEY: TTree    peak171;73      The root tree for singles
  KEY: TTree    peak171;72      The root tree for singles
  KEY: TTree    peak245;43      The root tree for singles
  KEY: TTree    peak245;42      The root tree for singles
  KEY: TTree    scatter;16      The root tree for singles
  KEY: TTree    scatter;15      The root tree for singles
  KEY: TH1D     latest_event_ID;1       latest_event_ID(#)
  KEY: TH1D     total_nb_primaries;1    total_nb_primaries(#)
  KEY: TTree    OpticalData;1   OpticalData
root [2] 
```

Figure 1: Output of .ls command

In order to get the content of a TTree, i.e. list of saved histograms or "branches", for example for Hits TTree, one can do:

root[1] `Hits->Show()`

This method is used to get one entry of a tree, i.e. if one does `Hits->Show(10)`, the output will be given for the 10th entry. Thus, if the argument is empty, as in the example above the output will is for the 0 entry (Figure 2).



```
root [2] Hits->Show()
======> EVENT:-1
 PDGEncoding     = 0
 trackID         = 0
 parentID        = 0
 trackLocalTime  = 0
 time            = 0
 edep            = 0
 stepLength      = 0
 trackLength     = 0
 posX            = 0
 posY            = 0
 posZ            = 0
 localPosX       = 0
 localPosY       = 0
 localPosZ       = 0
 momDirX         = 0
 momDirY         = 0
 momDirZ         = 0
 headID          = 0
 crystalID       = 0
 pixelID         = 0
 unused3ID       = 0
 unused4ID       = 0
 unused5ID       = 0
 photonID        = 0
 nPhantomCompton = 0
 nCrystalCompton = 0
 nPhantomRayleigh = 0
 nCrystalRayleigh = 0
 primaryID       = 0
 sourcePosX      = 0
 sourcePosY      = 0
 sourcePosZ      = 0
 sourceID        = 0
 eventID         = 0
 runID           = 0
 axialPos        = 0
```

Figure 2: Output of Show() command

3 Checking statistics of a TTree

To check how many events there are in a TTree without plotting histograms, one can open ROOT file in a terminal window and do:

root[1] `Hits->GetEntries()`

The output will be like:

```
(Long64_t) 235868
```

which means that in the example Hits tree there are 235868 saved events.

4 Smart plotting of your histograms (without TBrowser and python scripts)

To plot a histogram one should use option `TTree -> Draw("name_of_the_branch")`. For example, if you want to plot 1D, 2D or 3D histograms of energy and positions you could do
root[1] `Hits->Draw("edep")` for 1D (Figure 3, top)

root[2] `Hits->Draw("posX:posY")` for 2D, where the first argument, `posX` is ordinate axis and `posY` is abscissa axis (Figure 3, middle)

root[3] `Hits->Draw("posX:posY:posZ")` for 3D (Figure 3, bottom)

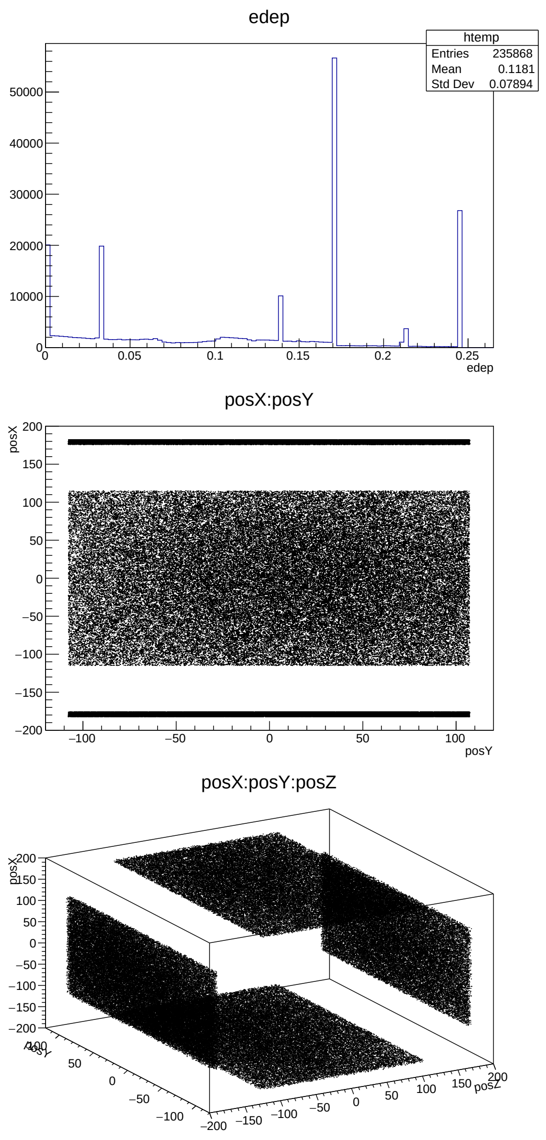
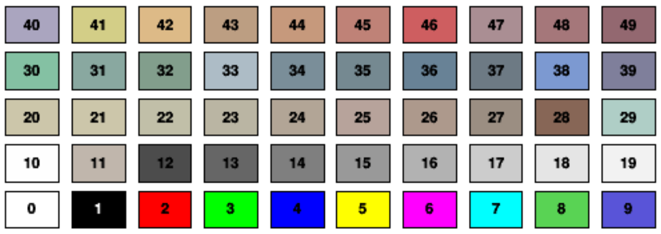


Figure 3: Output of Draw commands

4.1 Colors, markers, lines

4.1.1 Color

It is possible to change the colors, line and marker styles and size. To change the color one can use `TTree ->SetMarkerColor(n_of_color)` or `TTree ->SetLineColor(n_of_color)`. The `n_of_color` can be chosen from table in Figure 4, for more information check https://root.cern.ch/doc/v606/classTColor.html



40 41 42 43 44 45 46 47 48 49
30 31 32 33 34 35 36 37 38 39
20 21 22 23 24 25 26 27 28 29
10 11 12 13 14 15 16 17 18 19
0 1 2 3 4 5 6 7 8 9

Figure 4: Basic ROOT colors used as a Draw() option. For more information check: https://root.cern.ch/doc/v606/classTColor.html

The example of usage is in the following command and in Figure 5:

```
root[4]  Hits->SetLineColor(2)
root[5]  Hits->Draw("edep")
```

or to change marker color one can do:

```
root[4]  Hits->SetMarkerColor(2)
root[5]  Hits->Draw("edep")
```

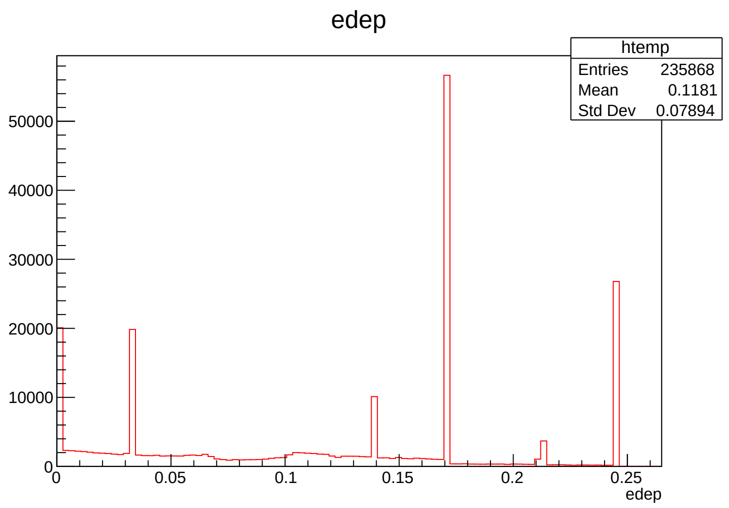


Figure 5: Drawing of the 1D histogram with a color option

4.1.2 Size

It is also possible to change size of lines with `TTree ->SetLineWidth(size)` (Figure 6):

```
root[4]  Hits->SetLineWidth(3)
root[5]  Hits->Draw("edep")
```

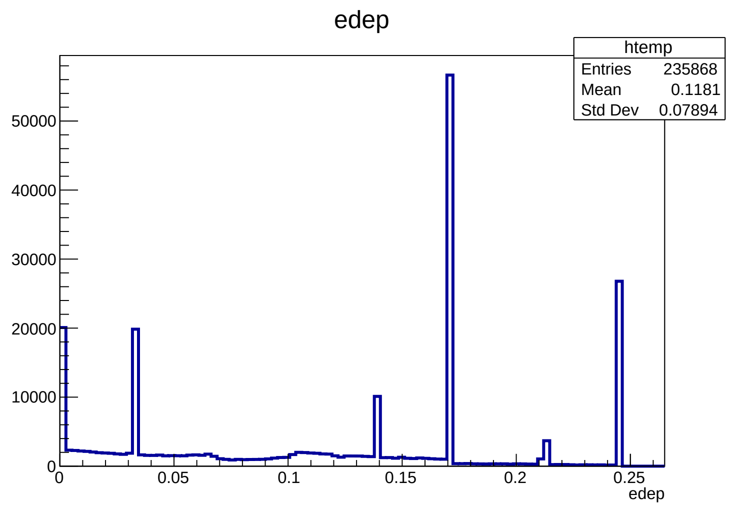


Figure 6: Drawing of the 1D histogram with a LineWidth option

4.1.3 Style

It is also possible to change style of lines and markers with `TTree ->SetLineStyle(n_of_style)` and `TTree ->SetLineStyle(n_of_style)`. The `n_of_style` can be chosen from table in Figure 7 and in Figure 8, for more information check
https://root.cern.ch/doc/v606/classTAttLine.html and
https://root.cern.ch/root/html534/TAttMarker.html

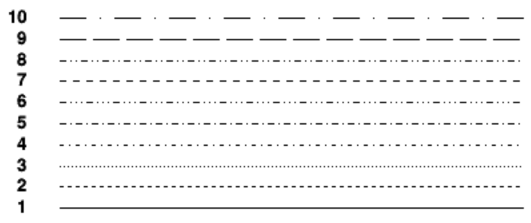


Figure 7: Basic ROOT line styles options. For more information check: https://root.cern.ch/doc/v606/classTAttLine.html

An example how to use these options is in the following and the results are illustrated in Figure 9 and in Figure 10:

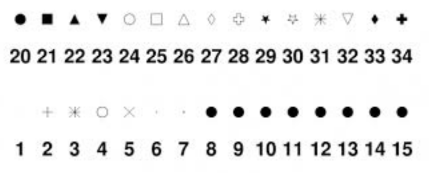


Figure 8: Basic ROOT marker styles options. For more information check: https://root.cern.ch/root/html534/TAttMarker.html

```
root[4] Hits->SetLineStyle(4)
root[5] Hits->Draw("edep")
```

and

```
root[4] Hits->SetMarkerStyle(4)
root[5] Hits->Draw("time:trackLength")
```

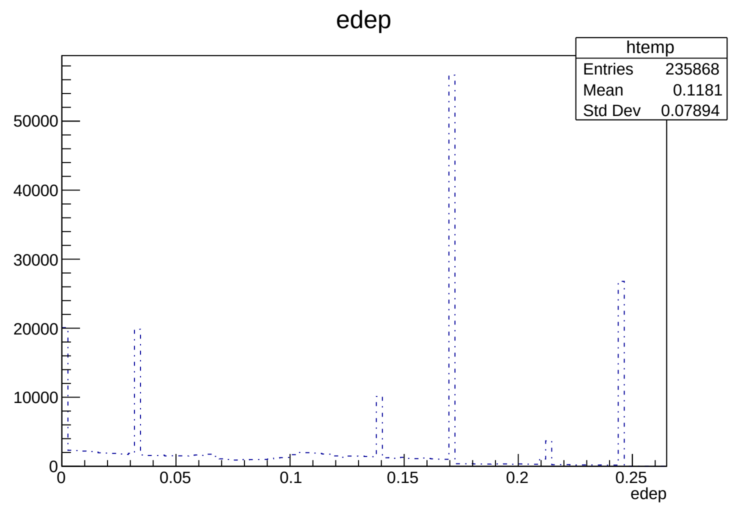


Figure 9: Drawing of the 1D histogram with a LineStyle option

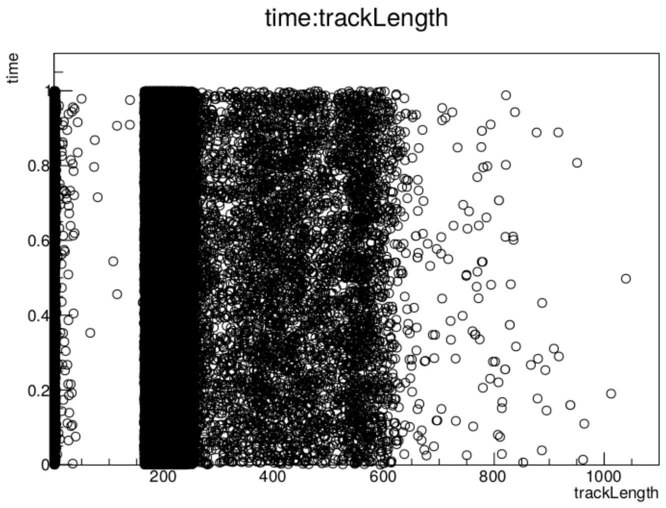


Figure 10: Drawing of the 2D histogram with a MarkerStyle option

4.2 How to apply a simple selection

It is also possible to apply a selection and after plot your variable. To do so one should use second option of the Draw() function: `TTree ->Draw("name_of_the_branch","selection")`. The several examples of cuts are presented here and plot the effect of them on `edep` variable:

```
root[4]  Hits->Draw("edep","trackID==1")
root[5]  Hits->Draw("edep","posX>0.5")
root[6]  Hits->Draw("edep","localPosX>=0.5")
root[7]  Hits->Draw("edep","processName==\"phot\"")   (variable is a string)
```

Or even more complicated selections like:

```
root[8]  Hits->Draw("edep","trackID==1 && posX>0.5")
root[9]  Hits->Draw("edep","trackID==1 || posX>0.5")
```

4.3 How to rebin a histogram

The default binning of a histogram in ROOT is 100 bins per axis (at least for 1D and 2D histograms). It is possible to change it and the simplest way is the following:
One has to define a histogram with needed parameters:

```
root[1] TH1F* h = new TH1F("h","h",50,0,0.3)
```

Here we have a histogram with 50 bins in a range from 0 to 0.3.
Next step is to plot your histogram using the defined histogram "h" (Figure 11):

```
root[2]  Hits->Draw("edep>>h","","")
```

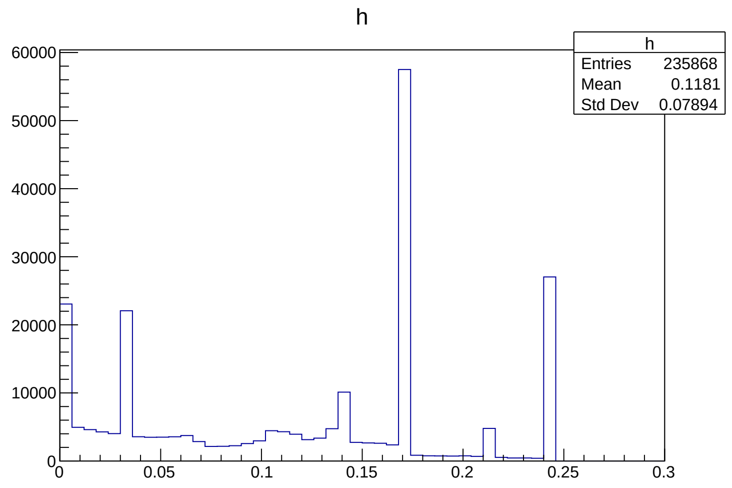


Figure 11: Drawing of rebinned 1D histogram

4.4 Superposition of two distributions

To superimpose two or more histograms one should write word ”same” in the third option of the Draw() function: `TTree ->Draw("name_of_the_branch","selection","same")`. For example, to obtain a histogram like in Figure 12 one can do:

```
root[4]  Hits->Draw("edep","")
root[5]  Hits->SetLineColor(2)
root[6]  Hits->Draw("edep","processName==\"phot\"","same")
```

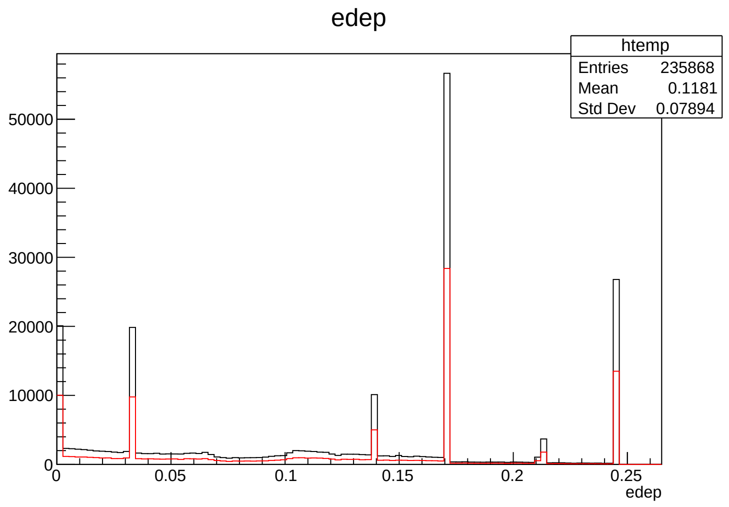


Figure 12: Drawing of two superposed the 1D histogram: one without any selection (black) and with a cut (red)

There is also a possibility to use `"esame"` option for the fast comparison of two histograms. Actually, this option plot error bars (`"e"` stands for that) but I would not recommend to rely on it and **calculate and plot your own error bars**. However, for a fast and easy superposition of two histograms without changing of line color it works perfectly (Figure 13):

```
root[4]  Singles->Draw("energy")
root[5]  Singles->Draw("energy","time<0.3","esame")
```

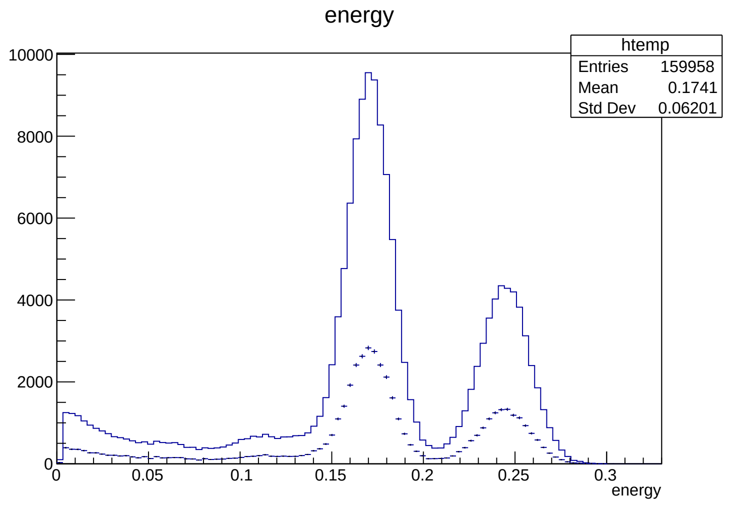


Figure 13: Drawing of two superposed the 1D histogram with "esame" option

4.5 Superposition of two distributions from different ROOT files

Sometimes it is useful to plot a superposition of two histograms from different ROOT files. In this case on start by opening the ROOT file 1:

```
> root -l YourOutputFile.root
```

or by an equivalent command directly in ROOT:

root[0] `TFile *_file0 = TFile::Open("YourOutputFile.root");`

and draw a histogram:

root[2] `Singles->Draw("energy")`

The next step is to open the second file by:

root[3] `TFile *_file1 = TFile::Open("YourOutputFile1.root");`

and draw the new histogram with ”same” or ”esame” option:

root[4] `Singles->Draw("energy","","esame")`

4.6 Simple fitting

It is possible to do a simple fit of your distribution. For this after drawing your histogram you need to go to the canvas window and select `Tools --> Fit Panel` . You will have new window with a Fit Panel as presented in Figure 14. There you can choose your fitting function, fitting method, fitting range etc. In the following example, the fit is done by Gaussian function in the range [0.13;0.21] MeV. The parameters of the fit are printed in the terminal window where you started ROOT and look like following:

```
 FCN=1259.74 FROM MIGRAD    STATUS=CONVERGED      75 CALLS       76 TOTAL
               EDM=1.82902e-12    STRATEGY= 1      ERROR MATRIX ACCURATE
  EXT PARAMETER                                   STEP         FIRST
  NO.   NAME      VALUE            ERROR          SIZE      DERIVATIVE
   1  Constant     9.05059e+03   4.05523e+01   5.29487e-01  -2.23836e-09
   2  Mean         1.70049e-01   4.42797e-05   7.60710e-07  -4.18082e-02
   3  Sigma        1.28126e-02   3.88904e-05   1.30065e-05  -8.44577e-04
```

More about the fitting options can be found on ROOT web page.

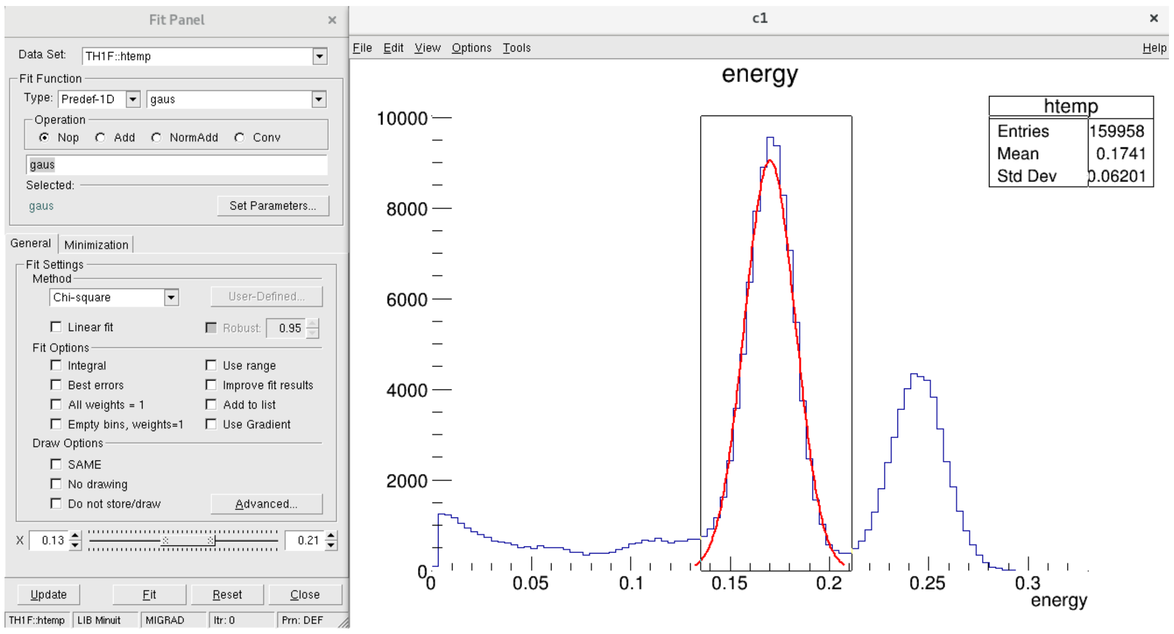


Figure 14: Fit panel and an example of fitted histogram

5 Scan option for a printout

Sometimes it is useful to printout the content of a branch, for example, in case when you want to study some anomalies. For this purpose one can use `Scan()` function. It is similar to `Draw()`, i.e. you also can apply cuts and plot several variables. For example, if one does:
root[4] `Hits->Scan("edep:posX","time<0.1&&posY>0")`
the output will be something like this:

```
************************************
*    Row   *       edep *       posX *
************************************
*        4 * 0.0198734 * 25.182537 *
*        5 *          0 * 25.227350 *
*       11 *          0 * -180.9978 *
*       14 * 0.2450000 * 104.99372 *
*       15 * 0.1710000 * -91.10610 *
*       18 * 0.2199750 * 58.401462 *
*       21 * 0.2450000 * -181.6459 *
*                   ...
*       60 * 0.1710000 * -47.08741 *
Type <CR> to continue or q to quit ==>
```

There are only first 25 lines in the output, one can press either "Enter" to continue or "q" to exit.

6 Simplest script to draw with ROOT

Sometimes it is useful to group the previous commands in a small script. Let's call it `my_script.C`, in order to run it one can do:

```
> root -l my_script.C
```

The `my_script.C` should contain something like this:

```
{
  TFile *_file0 = TFile::Open("YourOutputFile.root");
  Singles->Draw("energy");
  Singles->Draw("energy","time<0.3","esame");
},
```

where you open file at the beginning and after you can copy your plotting commands. **NB: The plotting commands are done for the last opened file. If you want to plot two histograms from different files, you have to open each time the needed file before plotting.**

7 Example of a script to make nice plots

I hear all the time a lot of complains that the ROOT plots are not beautiful. Thus, in this section I propose you a template to start for your plots. To run the script one should do:

```
> root -l my_script.C
```

The name of the main function in `my_script.C` must be the same as the name of your script file containing the following:

```
void my_script() {
  //remove the stat from upper right corner
  gStyle->SetOptStat(0);
   //remove the title
   gStyle->SetOptTitle(0);
  //define fonts sizes
  gStyle->SetTextSize(0.06);
  gStyle->SetLabelSize(0.06,"x");
  gStyle->SetLabelSize(0.06,"y");
  gStyle->SetLabelSize(0.06,"z");
  gStyle->SetTitleSize(0.06,"x");
  gStyle->SetTitleSize(0.05,"y");
  gStyle->SetTitleSize(0.06,"z");
  //define number of divisions on any axis, here is done only for "Y"
  gStyle->SetNdivisions(505,"y");
  gStyle->SetLineWidth(3);

     //define your ROOT file name
      TString filename = "YourOutputFile.root";
```

```
 // open the file
  TFile *f = TFile::Open(filename);
// get the TTree
  TTree *Tree = (TTree*)f->Get("Singles");

 // define the variable(s) of interest, type of variable must be respected
  Float_t energy;

 // define the branch(s) of interest
  TBranch *benergy;

 // Set branch address
  Tree->SetBranchAddress( "energy", &energy, &benergy);

 // Get number of events in the TTree
  const int n=(const int)Tree->GetEntries();

 // Define a histogram with 100 bins, on x from 0 to 0.3
TH1F* h = new TH1F("h","h",100,0,0.3);

 // Loop over events
for(int i=0;i<n;i++)
 {
  //get event i
  Tree->GetEntry(i);
  benergy->GetEntry(i);
  //print out the values
  cout<<i<<" "<<energy<<endl;
  //fill histogram
  h->Fill(energy);
  }

//Define canvas
TCanvas *can = new TCanvas("can","can",600,800);

//Define paramters of the canvas
 can->SetFillColor(0);
 can->SetBorderMode(0);
 can->SetBorderSize(3);
 can->SetBottomMargin(0.14);
 can->SetLeftMargin(0.16);
 can->SetFrameBorderMode(0);
 can->SetFrameLineWidth(3);
 can->SetFrameBorderMode(0);
```

```
   //Define parameters of the histogram
  h->SetLineWidth(2);
  h->SetLineColor(2);
  h->GetXaxis()->SetTitle("Energy, MeV");
  h->GetYaxis()->SetTitleOffset(1.6);
  h->GetYaxis()->SetTitle("Arbitrary units");
 //Draw histogram
  h->Draw();
  //Save cancas as .pdf
  can->SaveAs("energy.pdf");
}
```

This script could also be found here.

The output result is shown in Figure 15.

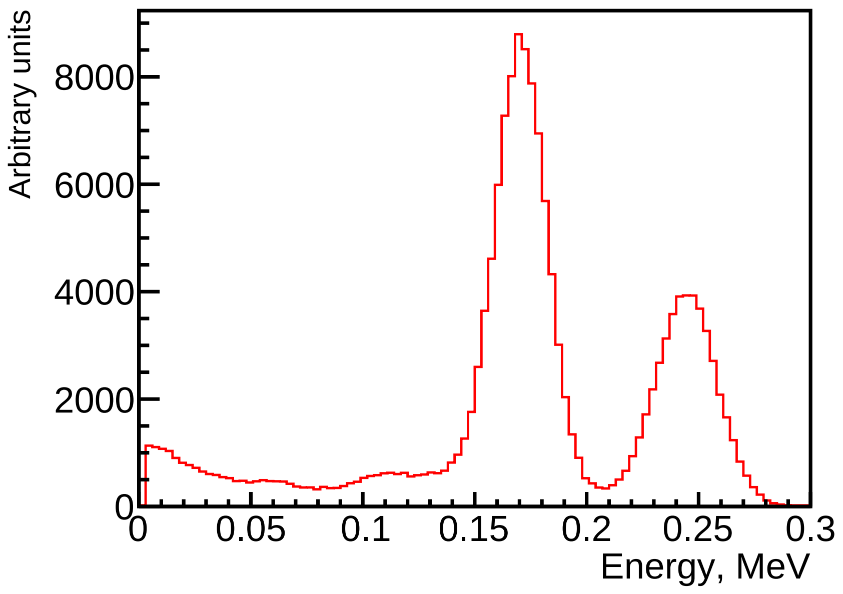


Figure 15: The output of the example of script making beautiful plots.

8 Adding a new variable to a TTree*

In this section I will just add a link to the script that indicates how to add a new variable. It is a script that adds a shift on energy which is different for each of four detection heads.

One can find it here: AddShiftedEnergy.C.