Introduction to ROOT: final part

(for good!)

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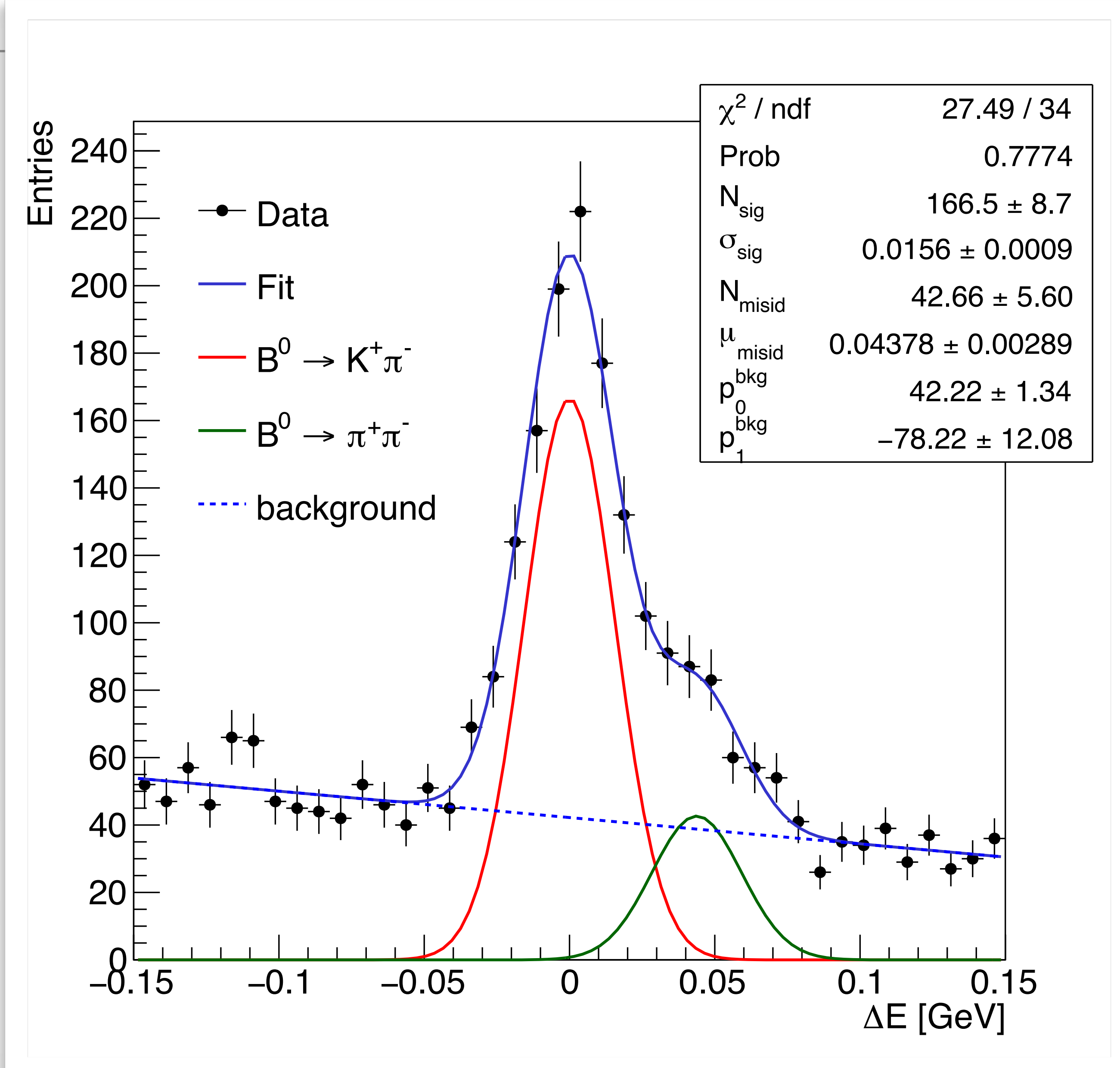
We made it?




```
 From this fit model,
Candidate in data histogram: 2777
Total candidates from fit   : 2777.01
Signal B->Kpi candidates    : 868.211
Mis-id B->pipi candidates   : 220.176
Background candidates       : 1688.62
```

The uncertainty is missing!

- We didn't compute the uncertainty on the signal yield yet!
- We used a gauss pdf for the signal, its integral (divided by the bin width w) gives the signal yield:

$$\text{pdf} = N e^{-\frac{(x-\mu)^2}{2\sigma^2}} \rightarrow S = N\sqrt{2\pi}\sigma/w$$

- To get the uncertainty on S, need to propagate the uncertainty from the fit on N and σ, considering their correlation.

Calculate S and its uncertainty

- Little addition in fitDeltaE.C

```
//option L = binned likelihood fit
//Use FitResultPtr to retreive all information about the fit
//Need to add the option S
TFitResultPtr fit = h_data->Fit("pdf","LRS");
//now we can get covariance matrix. We will store in a TMatrixDSym
TMatrixDSym cov = fit->GetCovarianceMatrix();
cov.Print();
```

- Now you have all information

```
cout << "======================================================" << endl;
cout << " Let's calculate the final result with its uncertainty " << endl;
//We can calculate the signal yield directly from the fit parameters
//of the signal pdf (gauss function)
double Nsig  = fit->Parameter(0);
double sigma = fit->Parameter(2);
double S = Nsig*sqrt(2.*TMath::Pi())*sigma/binW;

// and propagate the uncertainty
double errS = S * sqrt(cov(0,0)/Nsig/Nsig + cov(2,2)/sigma/sigma + 2*cov(0,2)/Nsig/sigma);

printf("The measurement of the signal yield is %.0f +- %.0f \n", S, errS);
//for curiosity let's print the correlation between Nsig and sigma,
//is it negligible?
printf("Corr(Nsig,sigma) = %.3f \n\n",cov(0,2)/sqrt(cov(0,0)*cov(2,2)));
```

Calculate S and its uncertainty

```
 From this fit model,
Candidate in data histogram: 2777
Total candidates from fit  : 2777.01
Signal B->Kpi candidates   : 868.211
Mis-id B->pipi candidates  : 220.176
Background candidates      : 1688.62
=======================================================
 Let's calculate the final result with its uncertainty
The measurement of the signal yield is 868 +- 47
Corr(Nsig,sigma) = -0.511
```

Exercise 1.

1. Compute the signal efficiency, $\epsilon = S(\text{selected})/S(\text{total})$, for each cut `bkg_killer`. Draw a graph to show the efficiency as a function of the cut value, drawing also the error on the efficiency (that you need to calculate): use the class TGraphErrors.

We will take `optimiseSelection.C` from the lesson and modify it.

Breaking down Exercise 1

```
#include "Riostream.h"
#include "TFile.h"
#include "TTree.h"
#include "TCanvas.h"
#include "TH1D.h"
#include "TGraph.h"

using namespace std;

void calculateEff(){

    //define the number of cuts to probe,
    //the range and the steps width
    const int ncuts = 15;
    double max_range = 1;
    double min_range = 0.7;
    double delta_cut = (max_range-min_range)/ncuts;

    //define the graph of the efficiency,
    //using TGraphErrors becasue I aslo want to
    //show the error on the efficiency
    TGraphErrors* g_eff = new TGraphErrors(ncuts);

    //Open file and take the tree
    TFile* file = TFile::Open("./simulation.root");
    TTree* tree = (TTree*) file->Get("simTree");
```

[TGraphErrors class]

Breaking down Exercise 1

```
    int tot_entries = tree->GetEntries("isBkg!=1");
    cout << "Total signal entries in the tree: " << tot_entries << endl;

    for(int icut=0; icut<ncuts; ++icut){

        //define the cut value to probe
        double cutval = min_range + icut*delta_cut;

        //put the cut in a string
        TString cutString = Form("bkg_killer > %.4f && isBkg!=1", cutval);

        //and retrieve the entries, directly from the tree, passing the selection
        double Nsig = tree->GetEntries(cutString);

        //calculate the efficiency and the error
        double eff = Nsig/tot_entries;
        double err_eff = [redacted]

        //just a check
        printf("cut value = %.3f, eff = %.4f +- %.4f \n",cutval, eff, err_eff);

        //put the results in the graph
        g_eff->SetPoint(icut,cutval,eff);
        g_eff->SetPointError(icut,0,err_eff);

    }
```

Signal only,
denominator of the efficiency

efficiency calculation

Set the point and the error in the graph

Breaking down Exercise 1

```
    printf("\n The signal efficiency for bkg_killer>0.92 is %.3f  \n",
    g_eff->Eval(0.92));

    //and draw the graph
    TCanvas* c = new TCanvas("c","c",800,600);
    g_eff->SetMarkerStyle(8);
    g_eff->SetMarkerSize(0.2);
    g_eff->GetXaxis()->SetTitle("cut value");
    g_eff->GetYaxis()->SetTitle("signal efficiency");
    g_eff->Draw("APL");

    return;
}
```

Draw the result

Breaking down Exercise 1

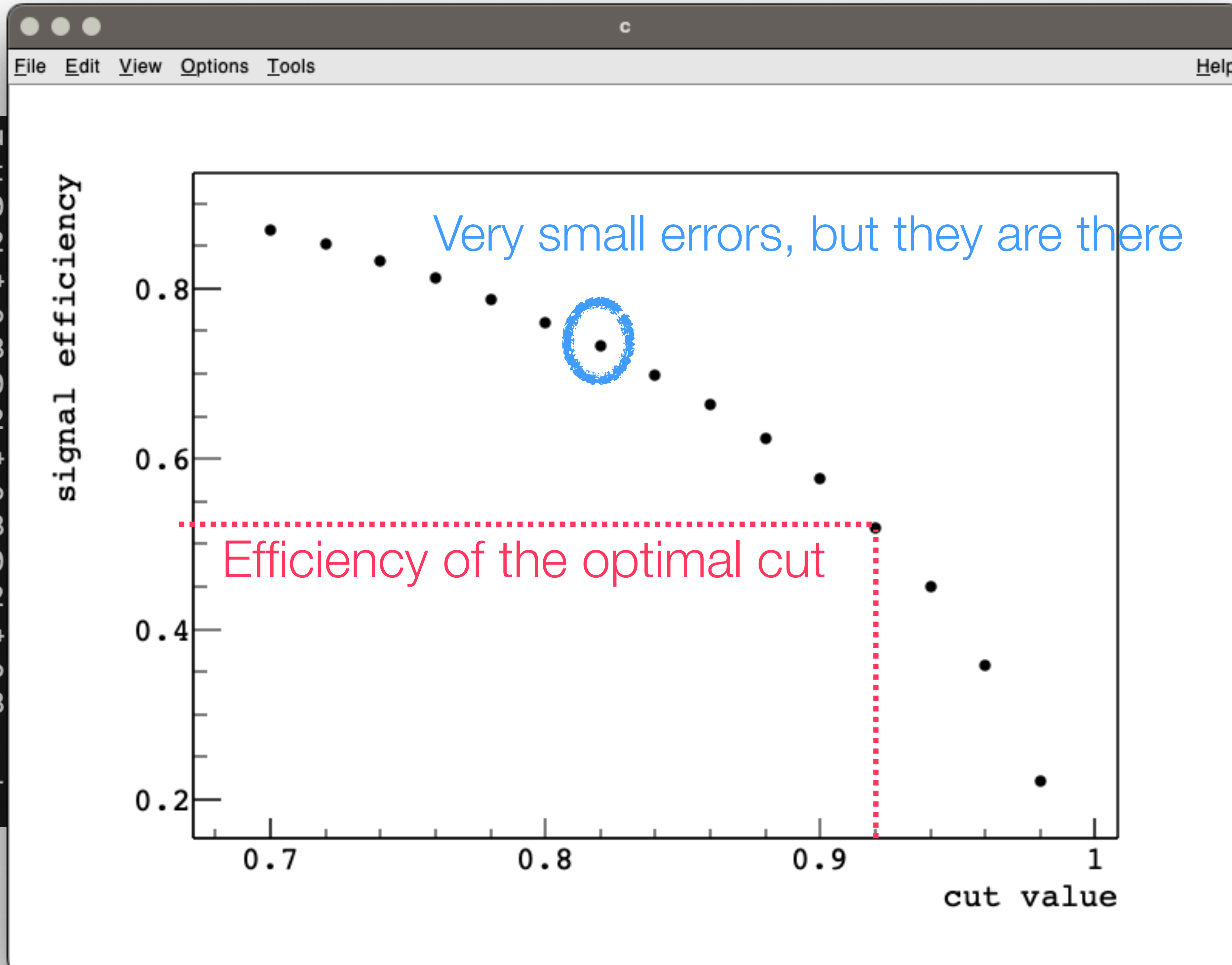
The output

```
Processing calculateEff.C...
Total signal entries in the tree: 21456
cut value = 0.700, eff = 0.8680 +- 0.0023
cut value = 0.720, eff = 0.8524 +- 0.0024
cut value = 0.740, eff = 0.8330 +- 0.0025
cut value = 0.760, eff = 0.8120 +- 0.0027
cut value = 0.780, eff = 0.7871 +- 0.0028
cut value = 0.800, eff = 0.7598 +- 0.0029
cut value = 0.820, eff = 0.7318 +- 0.0030
cut value = 0.840, eff = 0.6988 +- 0.0031
cut value = 0.860, eff = 0.6628 +- 0.0032
cut value = 0.880, eff = 0.6246 +- 0.0033
cut value = 0.900, eff = 0.5761 +- 0.0034
cut value = 0.920, eff = 0.5197 +- 0.0034
cut value = 0.940, eff = 0.4504 +- 0.0034
cut value = 0.960, eff = 0.3578 +- 0.0033
cut value = 0.980, eff = 0.2223 +- 0.0028

 The signal efficiency for bkg_killer>0.92 is 0.520
root [1]
```

Breaking down Exercise 1

The output

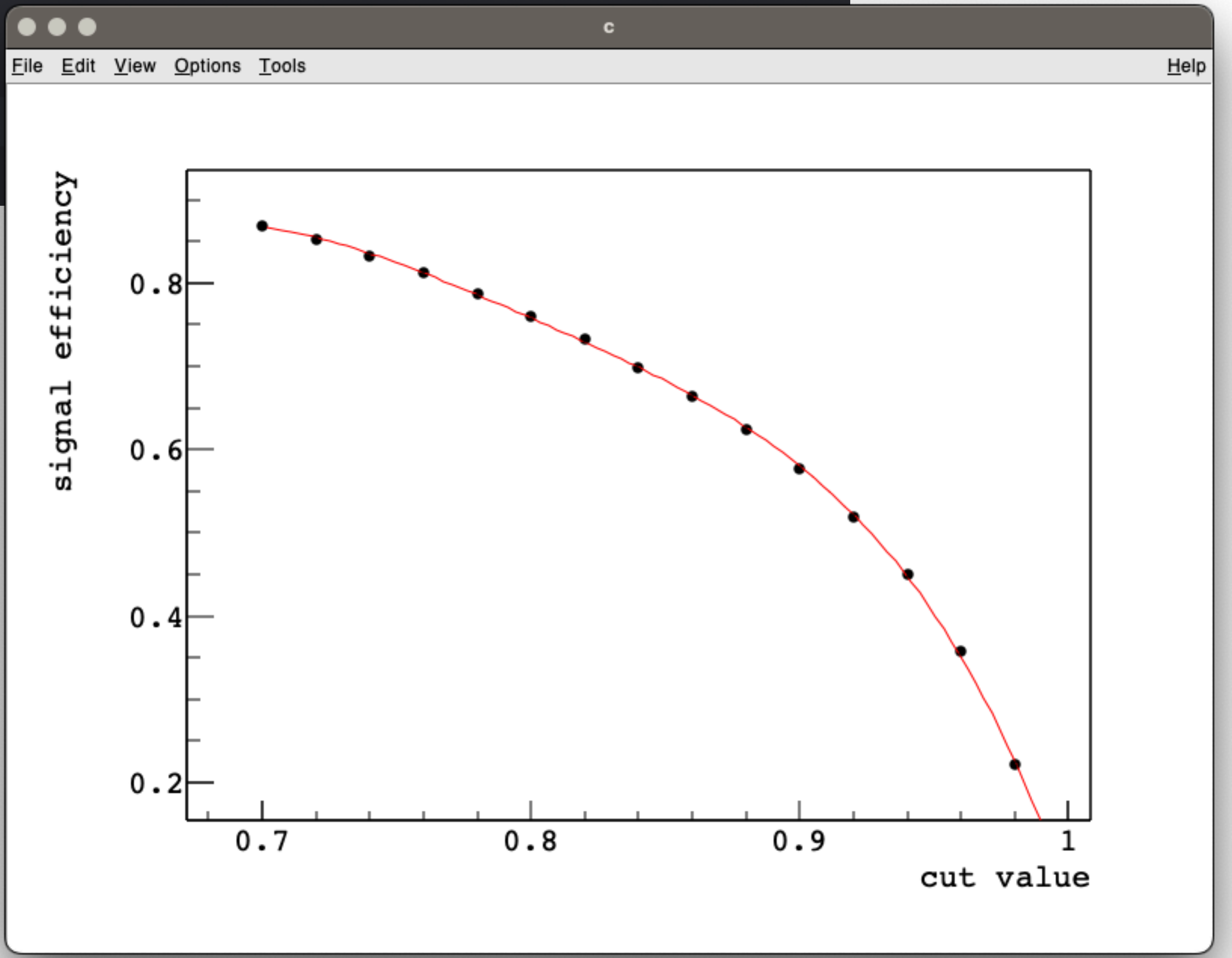
```
Processing calcu
Total signal ent
cut value = 0.70
cut value = 0.72
cut value = 0.74
cut value = 0.76
cut value = 0.78
cut value = 0.80
cut value = 0.82
cut value = 0.84
cut value = 0.86
cut value = 0.88
cut value = 0.90
cut value = 0.92
cut value = 0.94
cut value = 0.96
cut value = 0.98

 The signal effi
root [1]
```



Breaking down Exercise 1 (with a little extra)

Let’s add a fit to derive an efficiency function. We use a pol4.

```
TF1* efficiency = new TF1("efficiency","pol4",min_range,max_range);
efficiency->SetLineColor(kRed);
efficiency->SetLineWidth(1);

g_eff->Fit("efficiency","R");
g_eff->Draw("AP");
```



Fitting TGraphErrors with uncertainties on x

Does a (chi2) fit consider the uncertainties on x? How can it be?
Always have a look at the Reference Guide!

TGraphErrors fit:

In case of a TGraphErrors or TGraphAsymmErrors object, when x errors are present, the error along x, is projected along the y-direction by calculating the function at the points `x-ex_low` and `x+ex_high`, where `ex_low` and `ex_high` are the corresponding lower and upper error in x. The chi-square is then computed as the sum of the quantity below at each data point:

$$\frac{(y-f(x))^2}{ey^2+(\frac{1}{2}(exl+exh)f'(x))^2}$$

where x and y are the point coordinates, and ‘f’(x)`is the derivative of the function`f(x)`.

In case of asymmetric errors, if the function lies below (above) the data point, ey is `ey_low` (`ey_high`).

The approach used to approximate the uncertainty in y because of the errors in x is to make it equal the error in x times the slope of the line. This approach is called "effective variance method" and the implementation is provided in the function FitUtil::EvaluateChi2Effective

Exercise 2

2. What do you expect for the M distribution of the mis-id background? Draw it, by subtracting from the total distribution the signal and that of the non-B background (like we did for ΔE). Compare its distribution with that of the signal.

We will take `inspectB.C` from the lesson and modify it.

We will take this occasion to revisit `Sumw2()`

Breaking down Exercise 2

```
#include "Riostream.h"
#include "TFile.h"
#include "TTree.h"
#include "TCanvas.h"
#include "TH1D.h"
#include "TLegend.h"

using namespace std;

void compareM(){

    //open file and take the tree
    TFile* file = TFile::Open("simulation.root");
    TTree* tree = (TTree*) file->Get("simTree");

    int tot_entries = tree->GetEntries();
    cout << "Total entries in the tree: " << tot_entries << endl;

    //link the variables with tree banches
    double mass, bkg_killer;
    int bkg, sig;
    tree->SetBranchAddress("B_m",&mass);
    tree->SetBranchAddress("isBkg",&bkg);
    tree->SetBranchAddress("isSig",&sig);
    tree->SetBranchAddress("bkg_killer",&bkg_killer);

```

Breaking down Exercise 2

```
    //define an histogram to look at mass distribution
    TH1D* h_m_tot = new TH1D("h_m_tot",";mass [GeV/c^{2}]; Entries",40,5.25,5.30);

    //very very important to rember when manipulating histograms!!!
    h_m_tot->Sumw2();

    //clone the same histogram structure for signal, bkg, and unknown bkg
    TH1D* h_m_sig = (TH1D*) h_m_tot->Clone("h_m_sig");

    h_m_sig->Sumw2();//with Clone() we have already set it
                     //from the original TH1D, it will issue a "Warning"

    TH1D* h_m_bkg = (TH1D*) h_m_tot->Clone("h_m_bkg");
    TH1D* h_m_unknown = (TH1D*) h_m_tot->Clone("h_m_unknown");
```

IMPORTANT!!!

Not an issue…

```
Warning in <TH1D::Sumw2>: Sum of squares of weights structure already created
```

Breaking down Exercise 2

```
    //loop over the entries
    for(int iEntry; iEntry<tot_entries; ++iEntry){

        tree->GetEntry(iEntry);

        //skip all candidates below the optimal cut point
        if(bkg_killer<0.92) continue;

        //fill the histograms
        h_m_tot->Fill(mass);
        if(bkg) h_m_bkg->Fill(mass);
        else if(sig) h_m_sig->Fill(mass);

    }
```

Fill the histograms, just for the events that pass the cut

Breaking down Exercise 2

- Let's inspect just a bin (here 24): print out its content error for all histograms.
- Make then the operations to obtain the mass histogram for mis-id backgrd.

```
    int abin = 24;
    cout <<"\n From original histograms: " << endl;
    printf("Total  histo, bin %i content: %.1f +- %.1f \n", abin, h_m_tot->GetBinContent(abin), h_m_tot->GetBinError(abin) );
    printf("Signal histo, bin %i content: %.1f +- %.1f \n", abin, h_m_sig->GetBinContent(abin), h_m_sig->GetBinError(abin) );
    printf("Backgr histo, bin %i content: %.1f +- %.1f \n", abin, h_m_bkg->GetBinContent(abin), h_m_bkg->GetBinError(abin) );

    // subtract the signal
    h_m_unknown->Add(h_m_tot, h_m_bkg, 1, -1);
    h_m_unknown->Add(h_m_sig, -1);

    cout <<"\n The derived histogram: " << endl;
    printf("B->pipi histo, bin %i content: %.1f +- %.1f \n", abin, h_m_unknown->GetBinContent(abin), h_m_unknown->GetBinError(abin) );
    printf("B->pipi histo, sqrt(bin %i content): %.1f \n", abin, sqrt(h_m_unknown->GetBinContent(abin)) );

    double error_prop = sqrt(h_m_tot->GetBinError(abin)*h_m_tot->GetBinError(abin) +
                             h_m_sig->GetBinError(abin)*h_m_sig->GetBinError(abin) +
                             h_m_bkg->GetBinError(abin)*h_m_bkg->GetBinError(abin) );
    printf("B->pipi histo, from error propagation: %.1f \n\n",error_prop );
```

- Check the result. We expect:

$$N_{\text{unkn.}} = N_{\text{tot}} - N_{\text{bkg}} - N_{\text{sig}}$$

$$\sigma_{\text{unkn.}} = \sqrt{\sigma^2_{\text{tot}} + \sigma^2_{\text{bkg}} + \sigma^2_{\text{sig}}} = \sqrt{N_{\text{tot}} + N_{\text{bkg}} + N_{\text{sig}}}$$

Breaking down Exercise 2

- Check the result. We expect:

$$N_{\text{unkn.}} = N_{\text{tot}} - N_{\text{bkg}} - N_{\text{sig}}$$

$$\sigma_{\text{unkn.}} = \sqrt{\sigma^2_{\text{tot}} + \sigma^2_{\text{bkg}} + \sigma^2_{\text{sig}}} = \sqrt{N_{\text{tot}} + N_{\text{bkg}} + N_{\text{sig}}}$$

```
 From original histograms:
Total  histo, bin 24 content: 2432.0 +- 49.3
Signal histo, bin 24 content: 1667.0 +- 40.8
Backgr histo, bin 24 content: 326.0 +- 18.1

 The derived histogram:
B->pipi histo, bin 24 content: 439.0 +- 66.5
B->pipi histo, sqrt(bin 24 content): 21.0
B->pipi histo, from error propagation: 66.5
```

Breaking down Exercise 2

- Let's take out the command `Sumw2()`

$$N_{\text{unkn.}} = N_{\text{tot}} - N_{\text{bkg}} - N_{\text{sig}}$$

$$\sigma_{\text{unkn.}} = \sqrt{\sigma^2_{\text{tot}} + \sigma^2_{\text{bkg}} + \sigma^2_{\text{sig}}} = \sqrt{N_{\text{tot}} + N_{\text{bkg}} + N_{\text{sig}}}$$

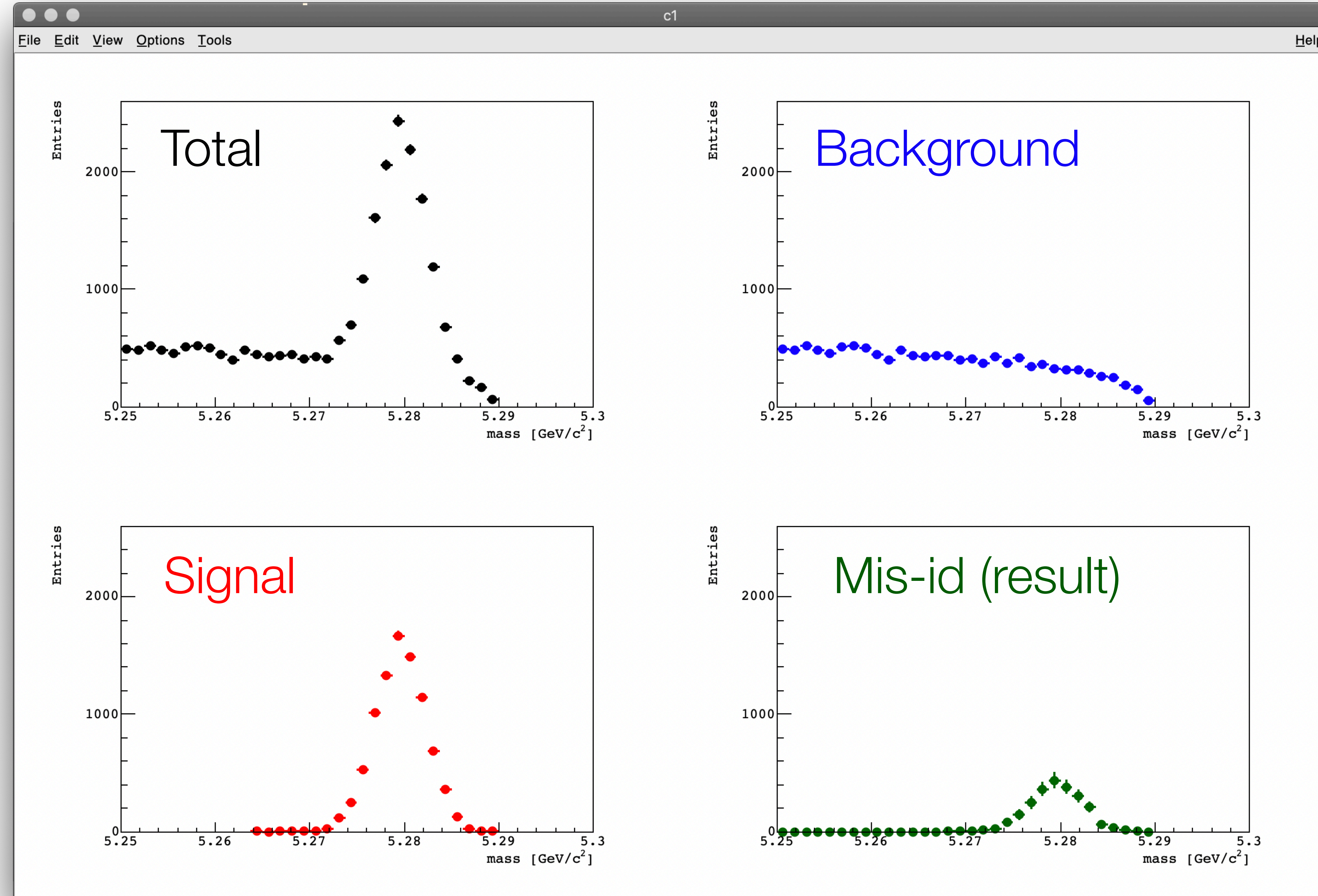
```
 From original histograms:
Total  histo, bin 24 content: 2432.0 +- 49.3
Signal histo, bin 24 content: 1667.0 +- 40.8
Backgr histo, bin 24 content: 326.0 +- 18.1

 The derived histogram:
B->pipi histo, bin 24 content: 439.0 +- 21.0
B->pipi histo, sqrt(bin 24 content): 21.0
B->pipi histo, from error propagation: 66.5
```

WRONG!!!

Breaking down Exercise 2

Just drawings…

```
//draw the histograms
TCanvas* c1 = new TCanvas("c1","c1",1200,800);
c1->Divide(2,2);
c1->cd(1);
h_m_tot->GetYaxis()->SetRangeUser(0,2600);
h_m_tot->Draw();
c1->cd(2);
h_m_bkg->GetYaxis()->SetRangeUser(0,2600);
h_m_bkg->SetMarkerColor(kBlue);
h_m_bkg->SetLineColor(kBlue);
h_m_bkg->Draw();
c1->cd(3);
h_m_sig->GetYaxis()->SetRangeUser(0,2600);
h_m_sig->SetMarkerColor(kRed);
h_m_sig->SetLineColor(kRed);
h_m_sig->Draw();
c1->cd(4);
h_m_unknown->GetYaxis()->SetRangeUser(0,2600);
h_m_unknown->SetMarkerColor(kMagenta);
h_m_unknown->SetLineColor(kMagenta);
h_m_unknown->Draw();
```


c1
File Edit View Options Tools
Help
Total
Background
Signal
Mis-id (result)
Entries
mass [GeV/c^2]
0
1000
2000
5.25
5.26
5.27
5.28
5.29
5.3

Breaking down Exercise 2 and 4

4. Instead of using `DrawNormalized()`, scale to 1 the histogram integral using the `Scale()` method of `TH1` (check the integral value) and normal `Draw()` method.

```
    //compare signal and B->pipi shapes:

    //first scale the histograms to the same unit area
    cout << "Signal histo integral: " << h_m_sig->Integral() << endl;
    cout << "B->pipi histo integral: " << h_m_unknown->Integral() << endl;

    h_m_sig->Scale(1./h_m_sig->Integral());
    h_m_unknown->Scale(1./h_m_unknown->Integral());

    cout << "After normalisation to unit area: " << endl;
    cout << "Signal histo integral: "  << h_m_sig->Integral() << endl;
    cout << "B->pipi histo integral: " << h_m_unknown->Integral() << endl;

    //a useful way to spot differences in shape is making the ratio of the distirbutions
    TH1D* h_ratio = (TH1D*) h_m_unknown->Clone("ratio");
    h_ratio->Divide(h_m_sig);

```

Use of scale to normalise to unit area

Another common operation on histograms

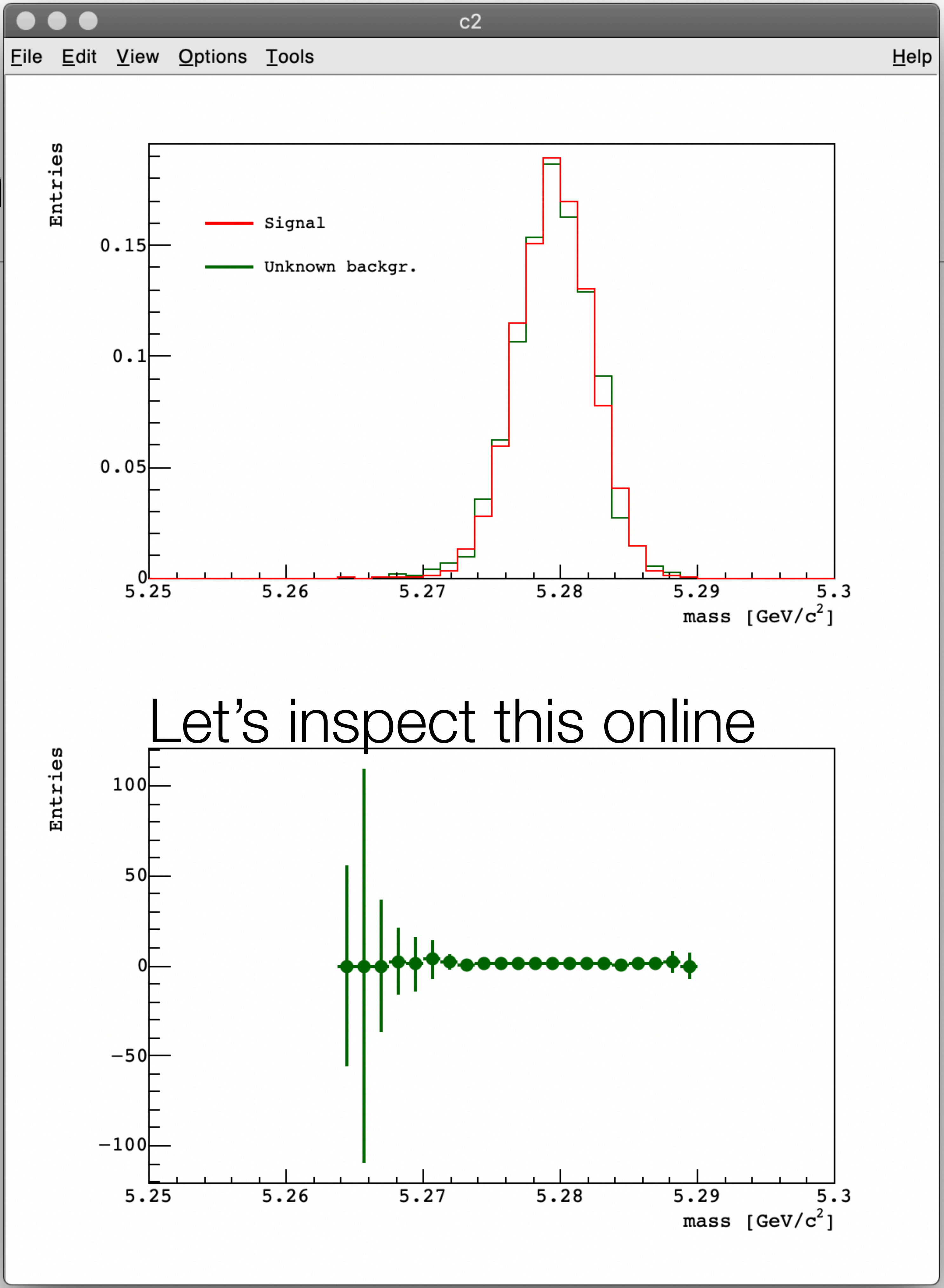
Breaking down Exercise 2 and 4

Draw the result

```
    TCanvas* c2 = new TCanvas("c2","c2",600,800);
    c2->Divide(1,2);
    c2->cd(1);
    h_m_unknown->Draw("histo");
    h_m_sig->Draw("histo same");

    //put a legend
    TLegend* leg = new TLegend(0.2,0.65,0.5,0.8);
    leg->AddEntry(h_m_sig,"Signal","L");
    leg->AddEntry(h_m_unknown,"Unknown backgr.","L");
    leg->Draw();

    c2->cd(2);
    h_ratio->Draw();
```

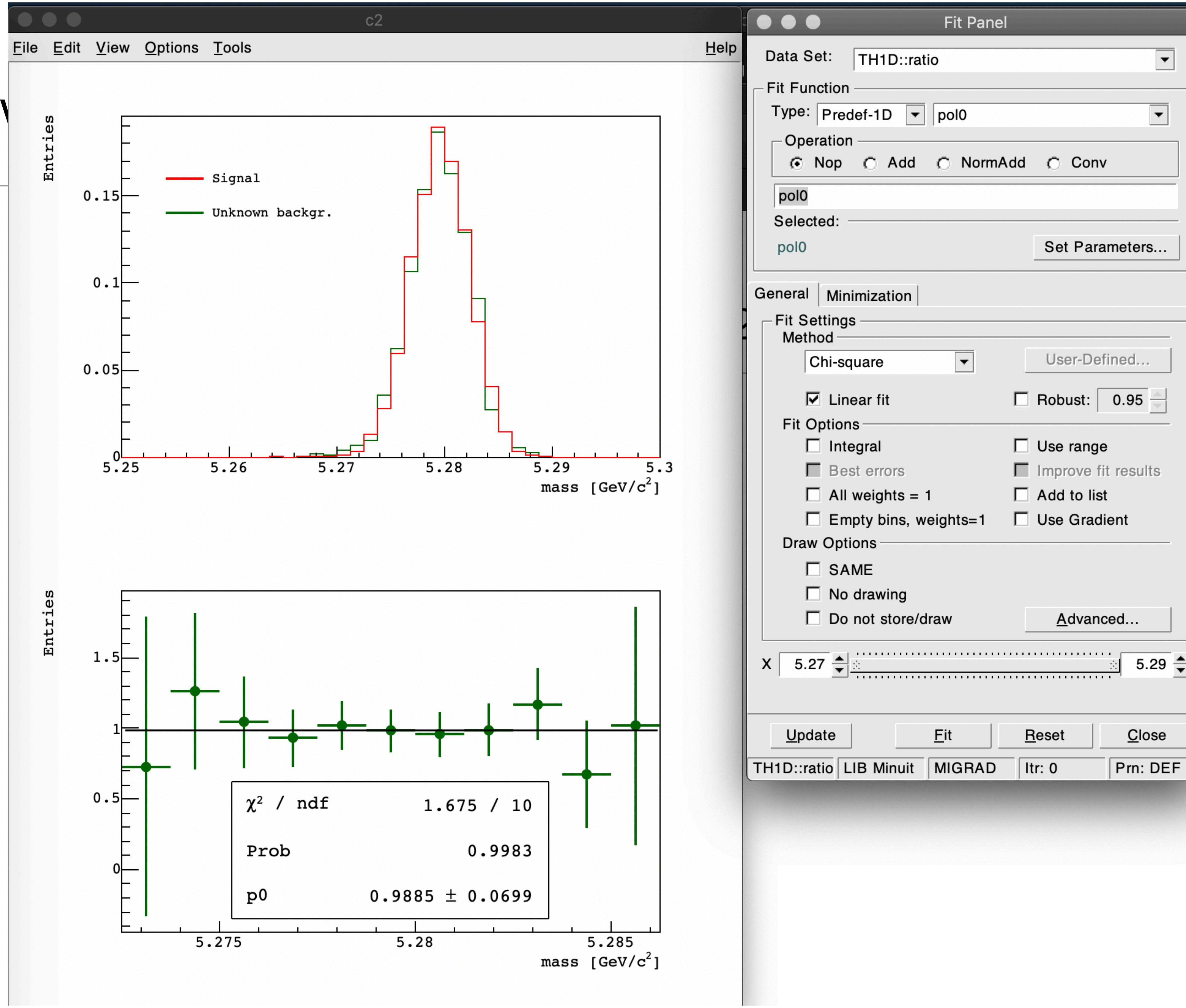
Breaking down

Draw the result



Let's inspect this online

Breaking do



Zoom in the core of the distributions, to check the flatness of the ratio.

To quantify it, we can make a fit of the point with a constant and see the probability of the χ^2. Here it is (ridiculously) high: this is because of the uncertainties of background distribution from the histograms' subtraction.

We made it!

- Congratulations for completing your (1st?) analysis with ROOT
- Hope this tour with a real-life example was useful (and also more interesting than a standard tutorial).
- Take your time to revisit all material and try it yourself.
  For questions, doubts, curiosity don't hesitate to contact me.
  We can organise Q&A sessions.
- If you are into data analysis at a particle physics experiment, **come to talk about opportunities in Belle II**.

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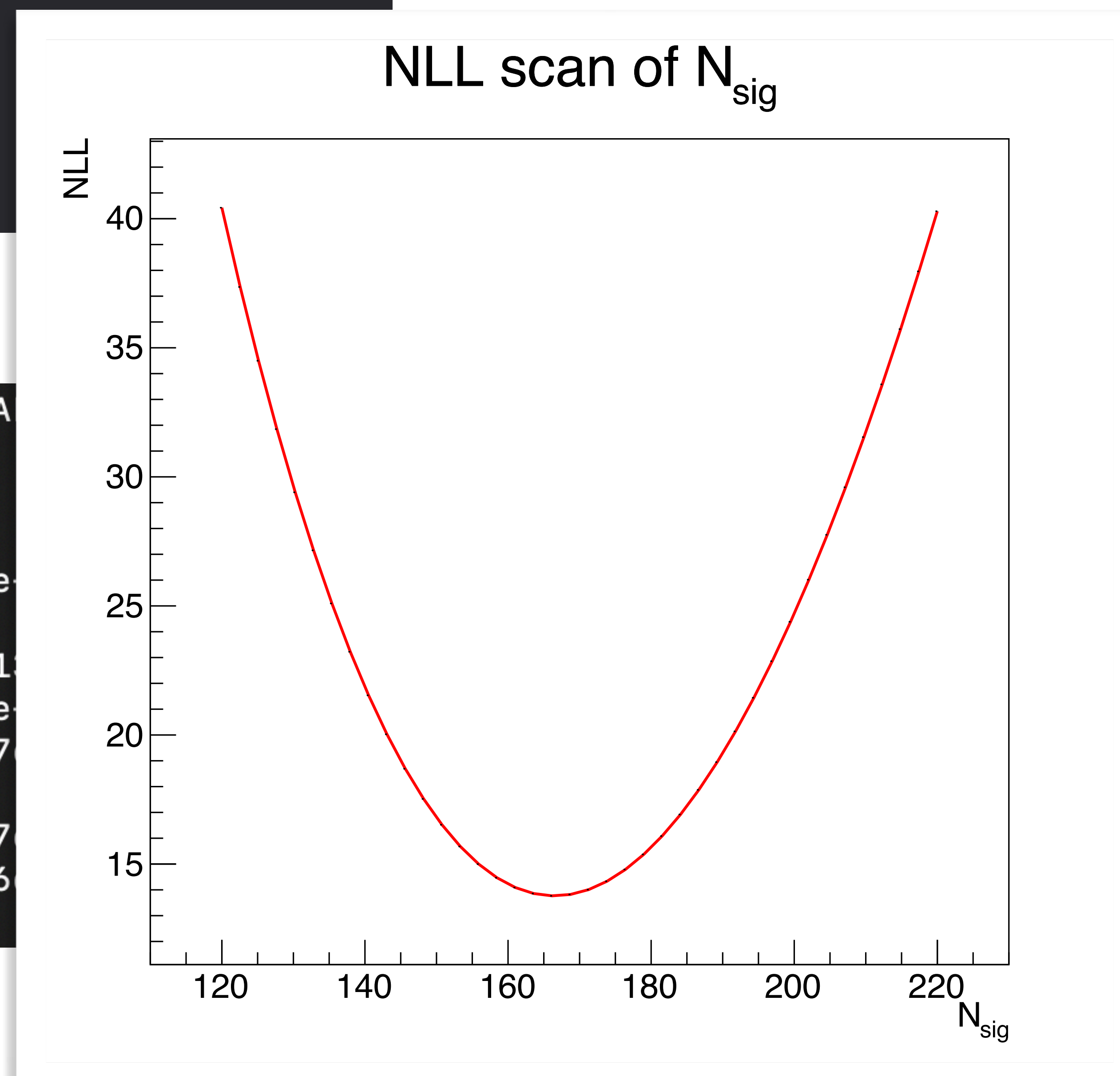
Extra

FCN (χ^2 or likelihood) scan

```
//Let's make a scan of the likelihood
//as a function of N_sig
TGraph* scan = new TGraph(40);
fit->Scan(0,scan,120,220);
TCanvas* c3 = new TCanvas("c3","c3",600,600);
scan->SetTitle("NLL scan of N_{sig}; N_{sig}; NLL");
scan->SetLineColor(kRed);
scan->SetLineWidth(2);
scan->Draw("APL");
c3->SaveAs("myScan.pdf");
```

NB: this is not a likelihood profile

```
FCN=13.7672 FROM MIGRAD    STATUS=CONVERGED     148 CA
                    EDM=5.36238e-08    STRATEGY= 1
 EXT PARAMETER                                  STEP
 NO.   NAME       VALUE            ERROR        SIZE
  1  N_{sig}       1.66476e+02   8.69389e+00   1.78671e
  2  #mu_{sig}     0.00000e+00     fixed
  3  #sigma_{sig}    1.56044e-02   8.92083e-04   1.5031
  4  N_{misid}     4.26560e+01   5.59930e+00   1.22986e
  5  #mu_{misid}     4.37828e-02   2.89346e-03   6.25797
  6  #sigma_{misid}    1.54440e-02     fixed
  7  p_{0}^{bkg}     4.22155e+01   1.34014e+00   2.98857
  8  p_{1}^{bkg}   -7.82222e+01   1.20763e+01   3.05956
                              ERR DEF= 0.5
```



Confidence regions

```
//Let's have a look: make 2D confidence regions
//1sigma contour: region enclosing 68.3% probability
TGraph* cont1sigma = new TGraph(50);
fit->Contour(0,2,cont1sigma,0.683);
cont1sigma->SetLineWidth(2);
cont1sigma->SetLineColor(kBlue+4);

//2sigma contour: region enclosing 95.5% probability
TGraph* cont2sigma = new TGraph(50);
fit->Contour(0,2,cont2sigma,0.955);
cont2sigma->SetLineStyle(2);
cont2sigma->SetLineWidth(2);
cont2sigma->SetLineColor(kBlue+2);

//3sigma contour: region enclosing 99.7% probability
TGraph* cont3sigma = new TGraph(50);
fit->Contour(0,2,cont3sigma,0.997);
cont3sigma->SetLineStyle(3);
cont3sigma->SetLineWidth(2);
cont3sigma->SetLineColor(kBlue);

//Draw all together, need to use TMultiGraph
TCanvas* c2 = new TCanvas("c2","c2",600,600);
TMultiGraph *mg = new TMultiGraph();
mg->SetTitle("Confidence regions for #sigma_{sig} vs N_{sig}; N_{sig}; #sigma_{sig} [Gev/c^{2}]");
mg->Add(cont1sigma,"l");
mg->Add(cont2sigma,"l");
mg->Add(cont3sigma,"l");
mg->Draw("a");
```

Confidence regions