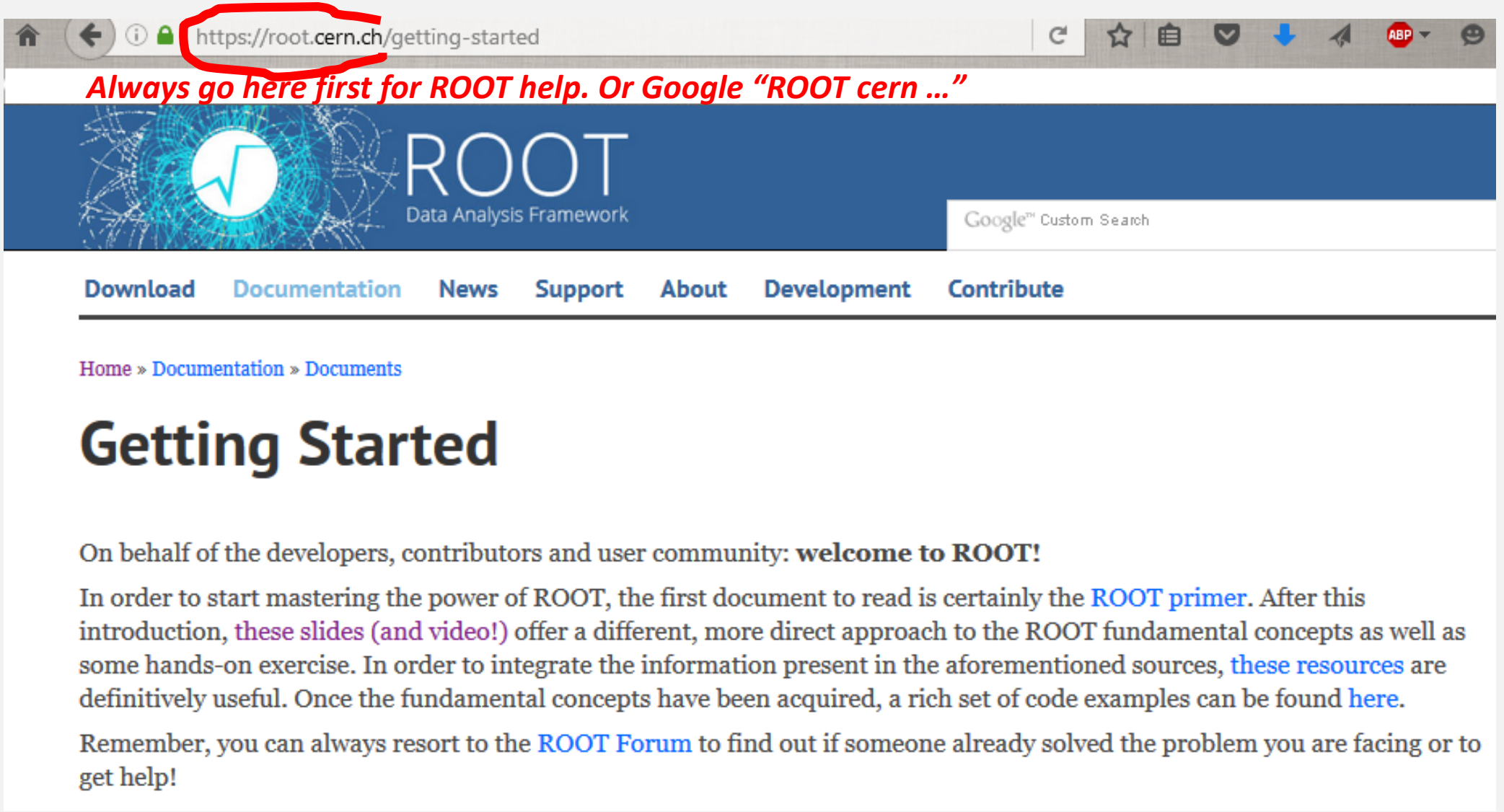
PHYS 6751: Graduate Nuclear & Particle Lab

- Basic Data Processing

Data processing needs & options

- In a nutshell, low energy nuclear physics data analysis comprises of:
  - Counting what you measured
  - Calibrating your measurement technique
  - Making cuts on and corrections to your data
    - E.g. calibrations, background subtractions
  - Fitting what you measured
    - *Often inferior to directly evaluating the data in a statistical way, e.g. finding peak centroids, peak widths, and background levels
- Analysis tools
  - Excel …could use it for our data, since it's simple, but please don't!
  - Gnuplot …good for simple, quick plotting & fitting
  - ROOT …the standard for nuclear physics analyses, highly flexible, C++ or Python, many built-in tools (including graphical tools), graphical interface available. Please use this! (will go over basics next lecture)

ROOT has a robust user community & extensive documentation



ROOT

- Powerful data analysis developed for particle physics analyses at CERN (née PAW)
- Numerous (documented) scientific & graphical tools based in C++
- Run as interpreted scripts or compiled codes
  - This simplifies things, but allows bad habits which occasionally bite you (memory leaks)

- Launch ROOT on the primary Edwards Lab machine (via PuTTY or from your built-in terminal):
  - `ssh -Y edwards.phy.ohiou.edu`
  - To start ROOT: `root -l` (the '-l' option prevents the annoying "splash screen" from displaying)
  - To exit ROOT: `.q`
  - Execute a script (a.k.a. macro) in ROOT: `.x myMacro.C`

ROOT example

- Let's analyze a simple data set by writing a ROOT macro*
- 1st read-in some data
  - Download γ-spectra from Paul King's website: http://inpp.ohiou.edu/~king/phys3702/tutorial/
  - Read-in the four available germanium spectra (^{22}Na, ^{60}Co, ^{137}Cs, ^{152}Eu)
    - In your favorite text editor, create a new file and enter it, e.g. `vi ProcessGeCalibrationData.C`
    - Write a script, something like:

```
void ProcessGeCalibrationData(){
  const Int_t Nchan=8192; //# of ADC channels
  Double_t Chan=0;
  Double_t Na22dat[Nchan];
  …

}
```

WARNING:
Copying & pasting from these slides into your text editor likely won't work (Special characters and hidden returns will be a problem).

*I'm not saying my code is the best way to do things. It's probably not, so please feel free to do things another way.

Write a script to read the data, something like:

```
void ProcessGeCalibrationData(){
  const Int_t Nchan=8192; //# of ADC channels
  Int_t Chan=0;
  Double_t Na22dat[Nchan];
  …
  ifstream fNa22dat;
  fNa22dat.open("germaniumdet_na22.txt");
  …
  for(int i=0;i<Nchan;i++){
    fNa22dat>>Chan>>Na22dat[Chan];
    …
    //check we're reading what we think we are:
    cout<<Chan<<" "<<Na22dat[Chan]<<endl;
    …
  }

}
```

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…now fill histograms with the data, like:

```
void ProcessGeCalibrationData(){
  [Code on previous slide]
  TH1F *hNa22raw=new TH1F("hNa22raw","hNa22raw",8192,0,8191);
  …
  for(int i=0;i<Nchan;i++){
    hNa22raw->Fill(i,Na22dat[i]);
    …
  }
}
```

 # bins *lower bin* *upper bin*

Tip:
You can save run-time by filling the histogram when you're assigning data to the array (on the previous slide). I do it separately here for clarity.

…& draw them, like:

```
void ProcessGeCalibrationData(){
  [Previous code]
  TCanvas *cAllSeparate=new TCanvas("cAllSeparate","cAllSeparate",10,10,600,600);
  cAllSeparate->Divide(2,2); splits the canvas into 2-by-2
  cAllSeparate->cd(1); make the first "pad" of the canvas (upper-left) the target for drawing
  hNa22raw->Draw();
  cAllSeparate->cd(2); make the second "pad" of the canvas (upper-left) the target for drawing
  hCo60raw->Draw();
  …
}
```

x,y coordinates of top-corner of canvas on screen *width & height of canvas on screen*

Tip:
Make sure you have x11 tunneling on for your connection and that you have a x11-forwarding program, such as Xming, running. Otherwise your plots won't display on your monitor.

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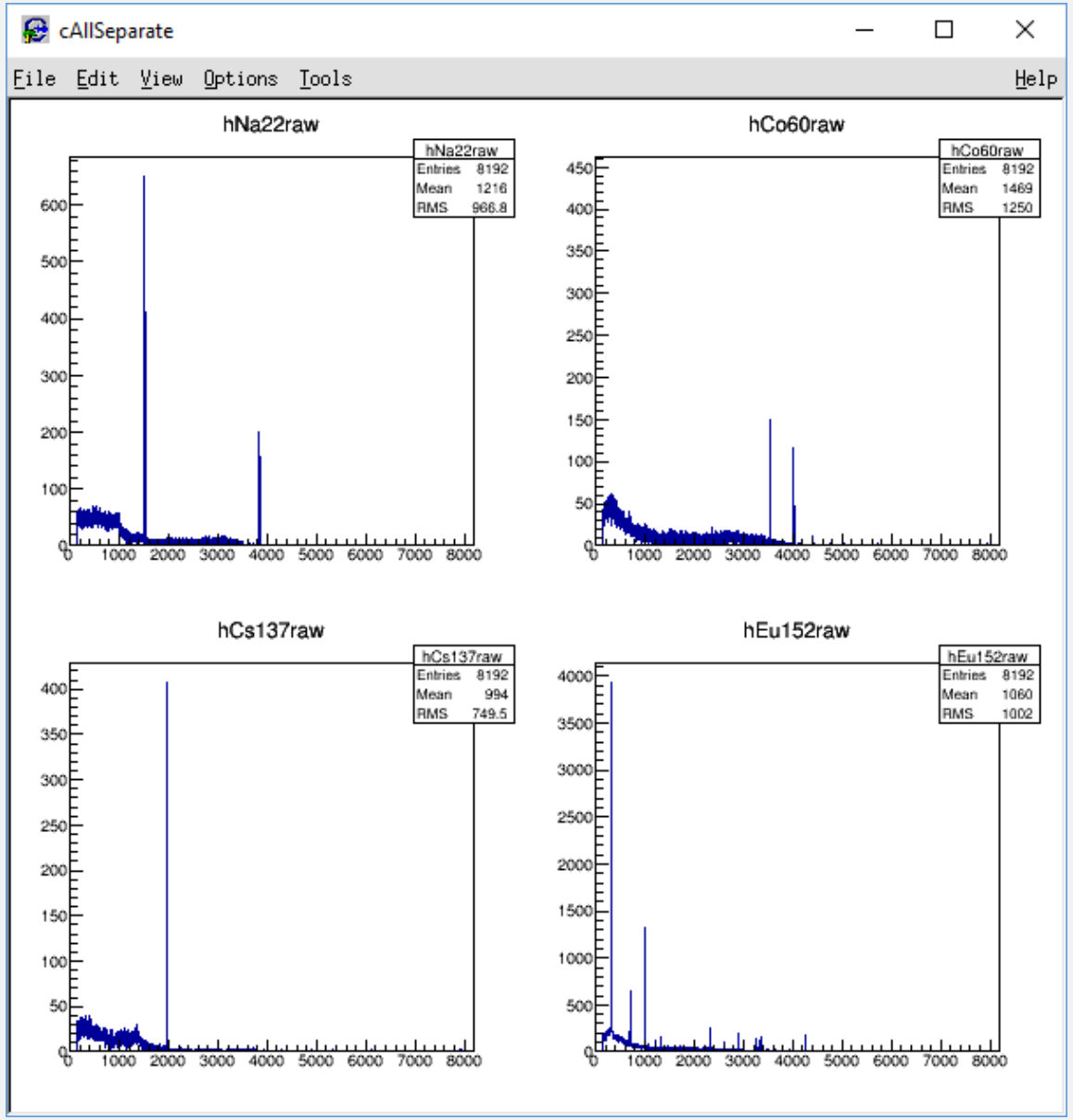
Bask in the glory of your plot



Get the Mean & Standard Deviation of the important peaks, like:

```
void ProcessGeCalibrationData(){
  [Previous code]
  const Int_t Na22_LowerBound1=1490;
  const Int_t Na22_UpperBound1=1540;
  hNa22raw->GetXaxis()->SetRange(Na22_LowerBound1,Na22_UpperBound1);
  Double_t Na22_counts1=hNa22raw->Integral(Na22_LowerBound1,Na22_UpperBound1);
  Double_t Na22_mean1=hNa22raw->GetMean();
  Double_t Na22_sig1=hNa22raw->GetRMS();
  Double_t Na22_Dmean1=Na22_sig1/sqrt(Na22_counts1);
  …
}
```

determine the ranges for your peak by looking at the spectrum or the text file

Do this for 2 sodium peaks, 2 cobalt peaks, and 1 cesium peak

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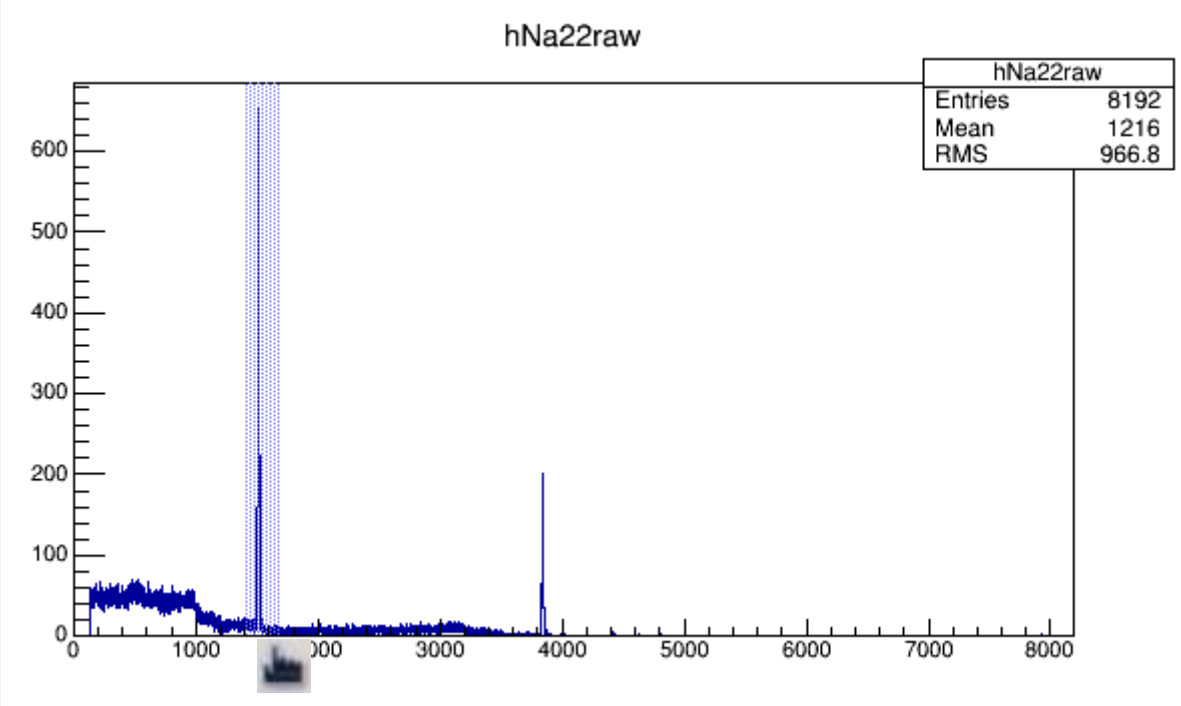
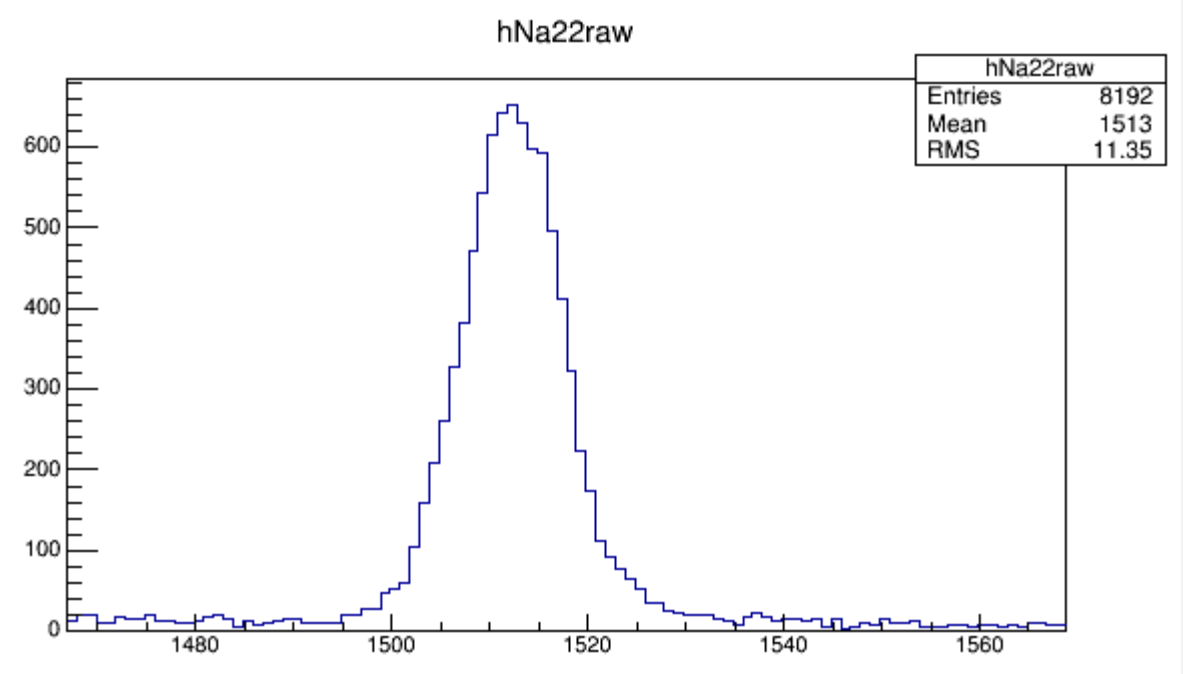
…zooming-in is a quick (non-automated) way to check your result





The standard deviation ("RMS" in ROOT) is highly range-dependent here because?

Create a graph of channel # vs energy, like:

```
void ProcessGeCalibrationData(){
  [Previous code]
  Double_t Na22_E1=511.00;
  Double_t Na22_E2=1274.54;
  TGraphErrors *gSourceCal=new TGraphErrors(1);
  gSourceCal->SetPoint(0,Na22_mean1,Na22_E1);
  gSourceCal->SetPoint(1,Na22_mean2,Na22_E2);
  gSourceCal->SetPointError(0,Na22_Dmean1,0.);
  gSourceCal->SetPointError(1,Na22_Dmean2,0.);
  gSourceCal->SetPoint(2,Co60_mean1,Co60_E1);
  …
  TCanvas *cCalFn=new TCanvas("cCalFn","cCalFn",500,10,400,300);
  cCalFn->cd();
  gSourceCal->SetMarkerStyle(7);
  gSourceCal->Draw("APE");
}
```

From Gordon Gilmore's Practical Gamma-ray Spectrometry Appendix B:

^{22}Na: 511.00 keV, 1274.54 keV
^{60}Co: 1173.23 keV, 1332.49 keV
^{137}Cs: 661.66 keV
^{152}Eu: You'll obtain these using the calibration

**uncertainties are on the ~eV level, so don't bother including them*

The "A" option is needed for the first graph you draw on a canvas pad. The "P" option means draw points. The "E" option means draw error bars.
…many more options exist

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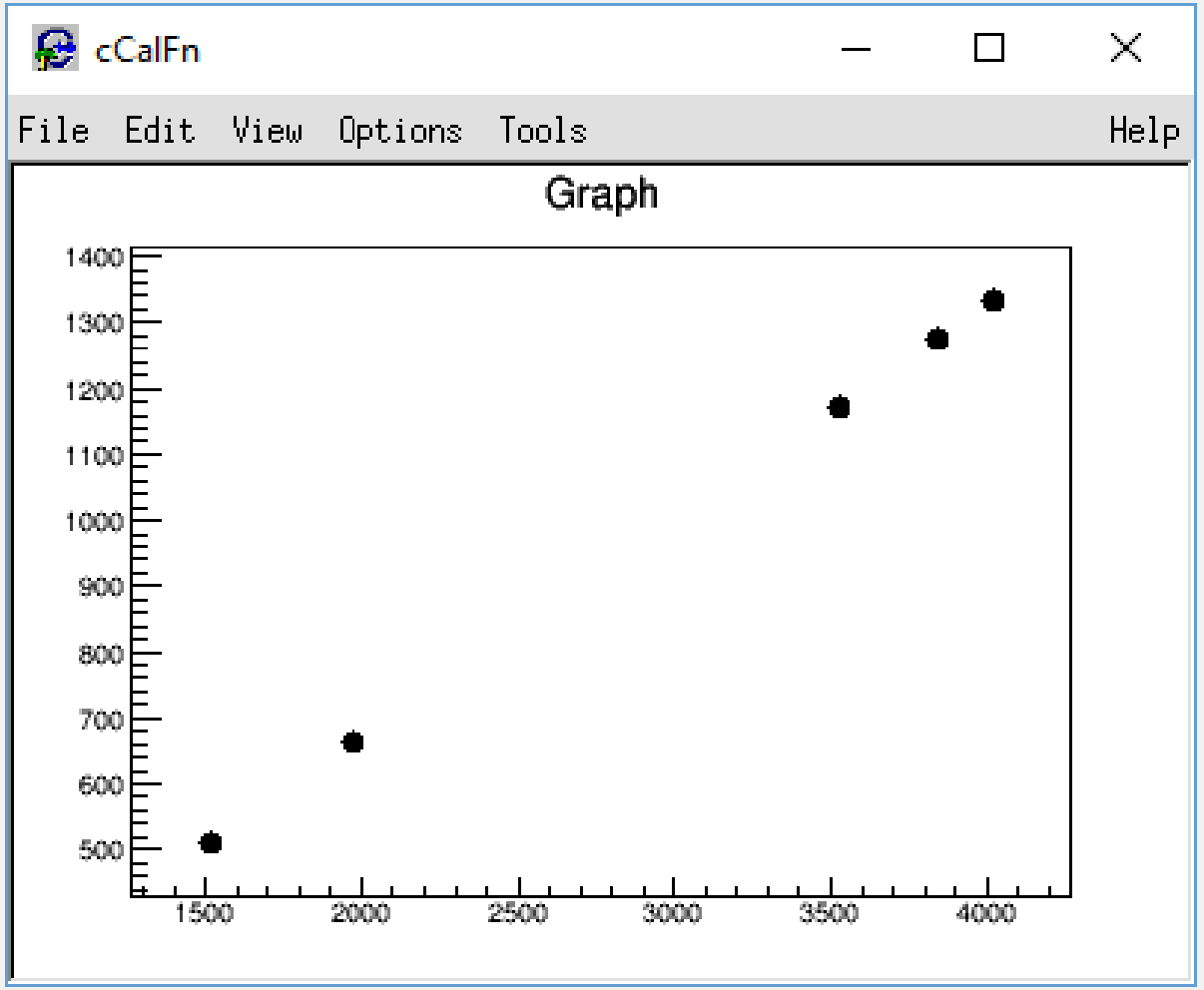
Bask in the glory of your plot



Fit the channel # vs energy graph to obtain an energy calibration, like:

```
void ProcessGeCalibrationData(){
  [Previous code]
  TF1 *fnQuad=new TF1("fnQuad","[0]+[1]*x+[2]*x*x");
  fnQuad->SetParameter(0,10);
  fnQuad->SetParameter(1,0.5);
  fnQuad->SetParameter(2,0.0001);

  gSourceCal->Fit("fnQuad");
  Double_t yint=fnQuad->GetParameter(0);
  Double_t slope=fnQuad->GetParameter(1);
  Double_t curv=fnQuad->GetParameter(2);
  Double_t Dyint=fnQuad->GetParError(0);
  Double_t Dslope=fnQuad->GetParError(1);
  Double_t Dcurv=fnQuad->GetParError(2);
  cout<<" "<<endl;
  cout<<yint<<" "<<slope<<" "<<curv<<endl;
  cout<<Dyint<<" "<<Dslope<<" "<<Dcurv<<endl;
}
```

Simple functions like this are built-in …but that's boring

guesses for parameters made from looking at the graph

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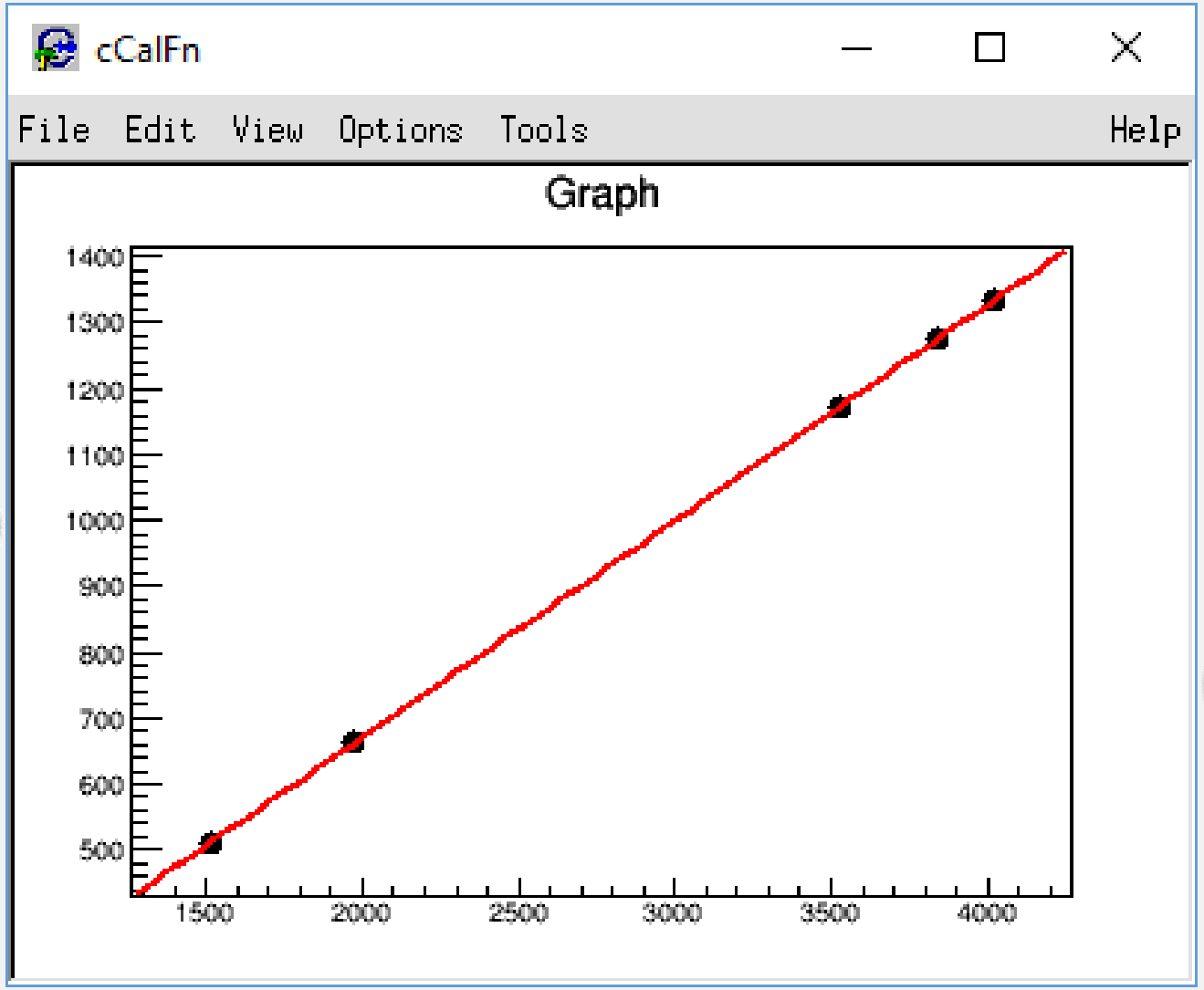
Bask in the glory of your plot



Create & Plot fit residuals, like:

```
Double_t ReturnYerror(Double_t x, Double_t y, Double_t dy, Double_t m, Double_t dm,
Double_t c, Double_t dc){
  //f(x)=a+b*x+c*x^2
  //-->df|x= SQRT{[(df/da)|x*(da)]^2 + [(df/db)|x*(db)]^2 + [(df/dc)|x*(dc)]^2}
  Double_t YError=sqrt(pow(1.*dy,2.)+pow(x*dm,2.)+pow(x*x*dc,2.));
  return(YError);
}

void ProcessGeCalibrationData(){
  [Previous code]
  TGraphErrors *gFitResid=new TGraphErrors(1);
  gFitResid->SetPoint(0,Na22_mean1,fnQuad->Eval(Na22_mean1)-Na22_E1);

  gFitResid->SetPointError(0,Na22_Dmean1,ReturnYerror(Na22_mean1,yint,Dyint,slope,
                           Dslope,curv,Dcurv));
  …
  TCanvas *cResid=new TCanvas("cResid","cResid",10,500,400,400);
  cResid->cd();
  gFitResid->SetMarkerStyle(7);
  gFitResid->Draw("APE");
}
```

Uncertainty propagation from Chapter 3 of John Taylor's Error Analysis

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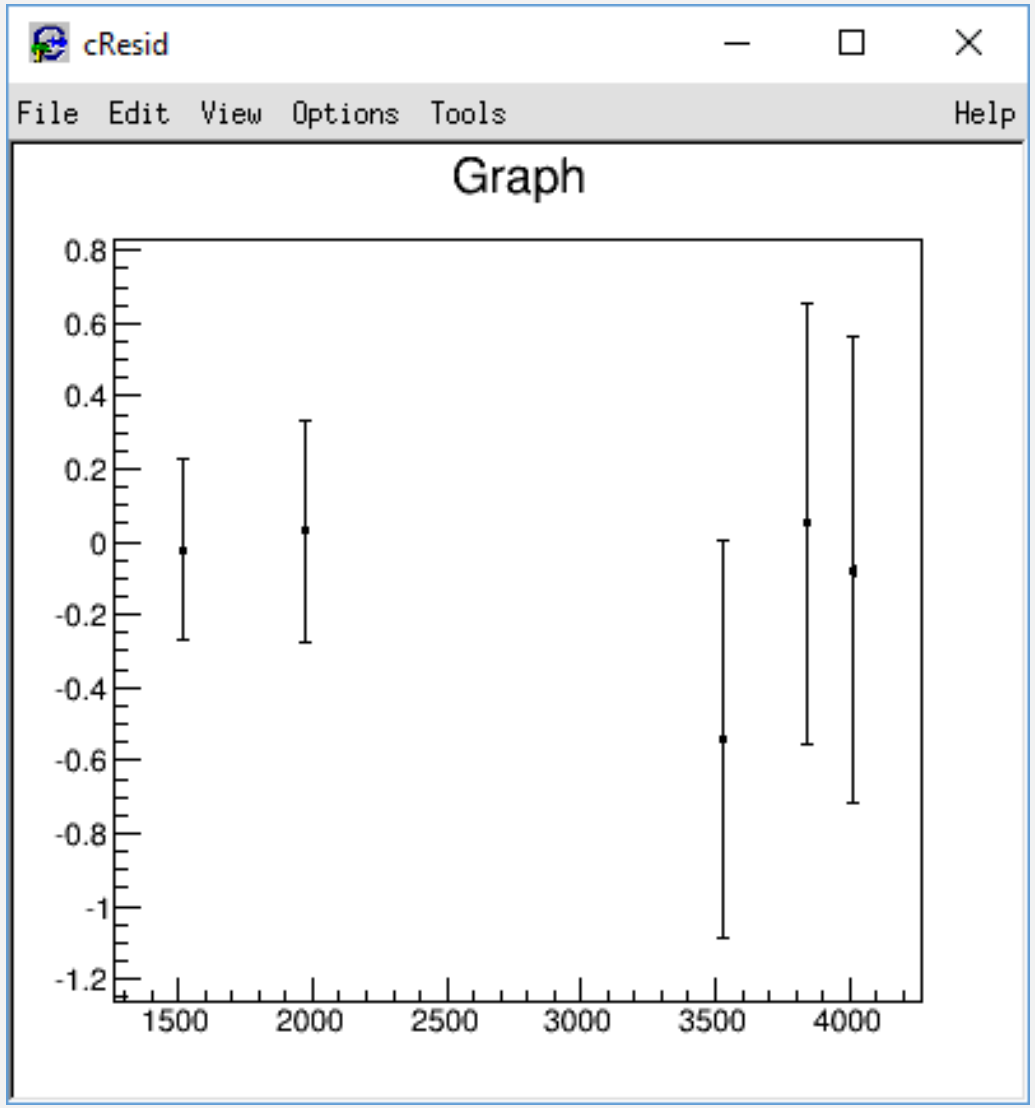

Now make a nice looking calibrated spectrum for ^{152}Eu, like:

```
[Previous code]
void ProcessGeCalibrationData(){
  [Previous code]
  TH1F *hEu152cal=new TH1F("hEu152cal","hEu152cal",8192,0,2705);
  for(Int_t i=0;i<Nchan;i++){
    hEu152cal->Fill(fnQuad->Eval((double)i),Eu152dat[i]);
  }
  TCanvas *cCalSpec=new TCanvas("cCalSpec","cCalSpec",10,10,600,400);
  cCalSpec->cd();
  gROOT->SetStyle("Pub");
  hEu152cal->GetXaxis()->SetTitle("#gamma-ray energy [kev]");
  hEu152cal->GetXaxis()->SetTitleFont(42);
  hEu152cal->GetXaxis()->SetTitleSize(0.05);
  hEu152cal->GetXaxis()->SetTitleOffset(0.9);
  hEu152cal->GetXaxis()->SetLabelSize(0.04);
  hEu152cal->GetXaxis()->CenterTitle();
  hEu152cal->GetXaxis()->SetNdivisions(510);
  hEu152cal->GetYaxis()->SetTitle("^{152}Eu counts");
  …
  hEu152cal->SetLineColor(1);
  hEu152cal->SetLineStyle(1);
  hEu152cal->SetLineWidth(1);
  cCalSpec->SetLogy();
  hEu152cal->Draw();
}
```

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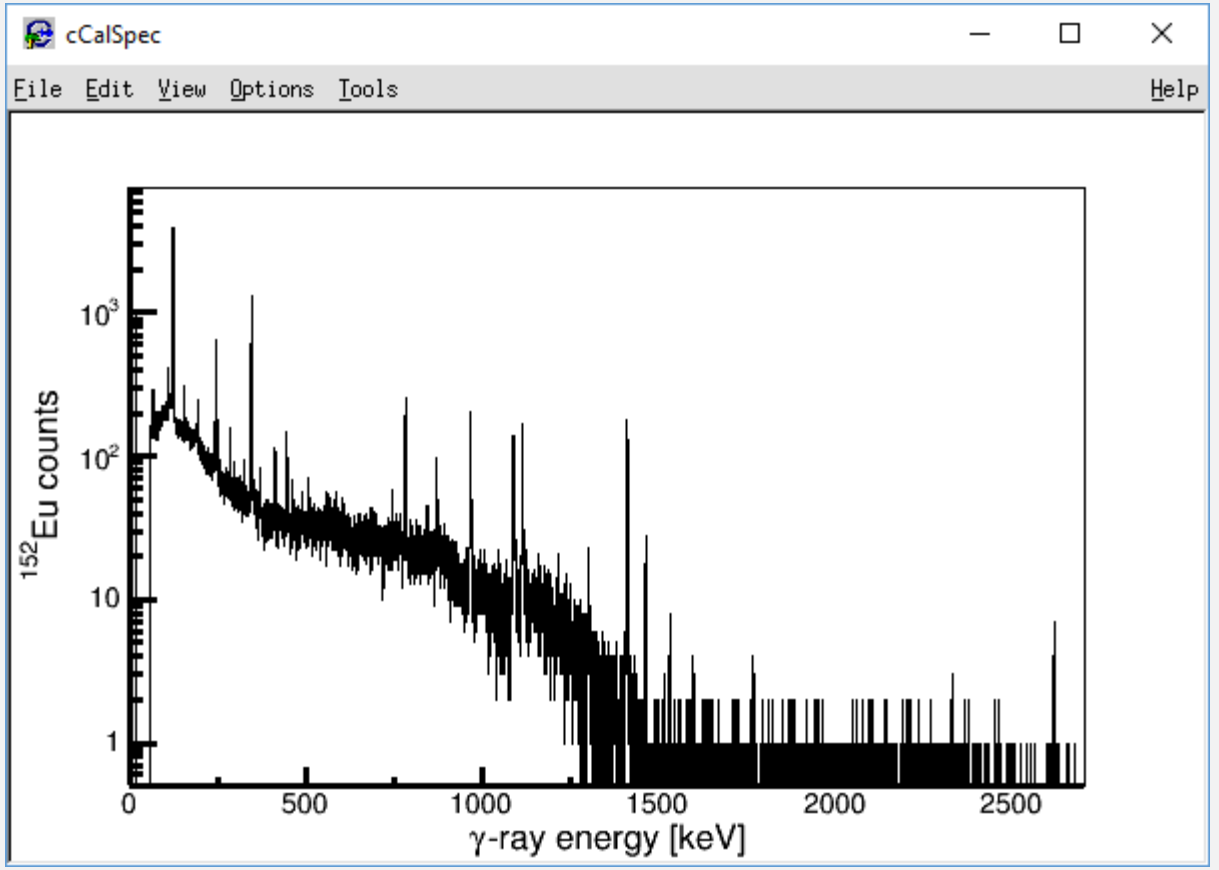
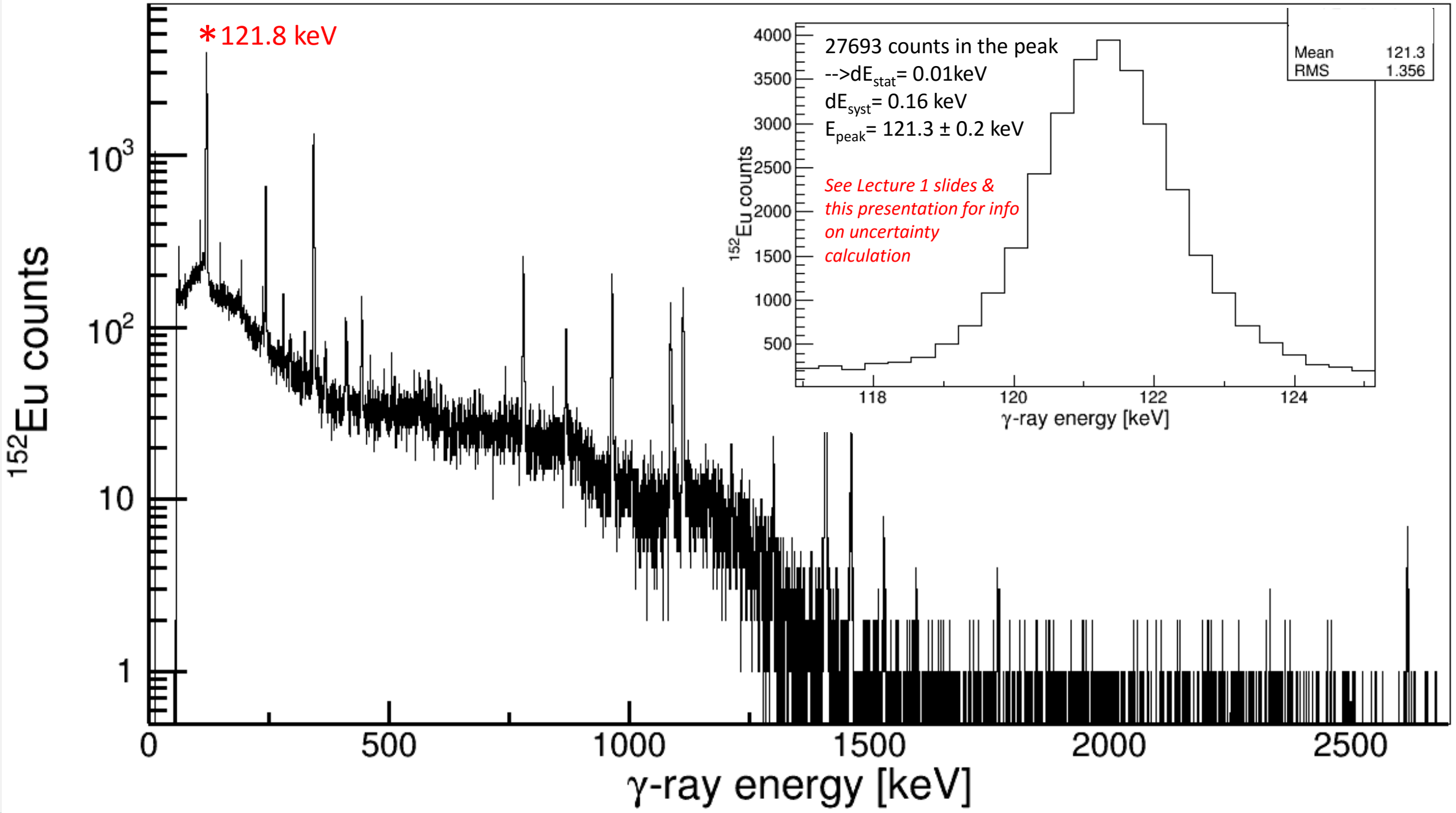
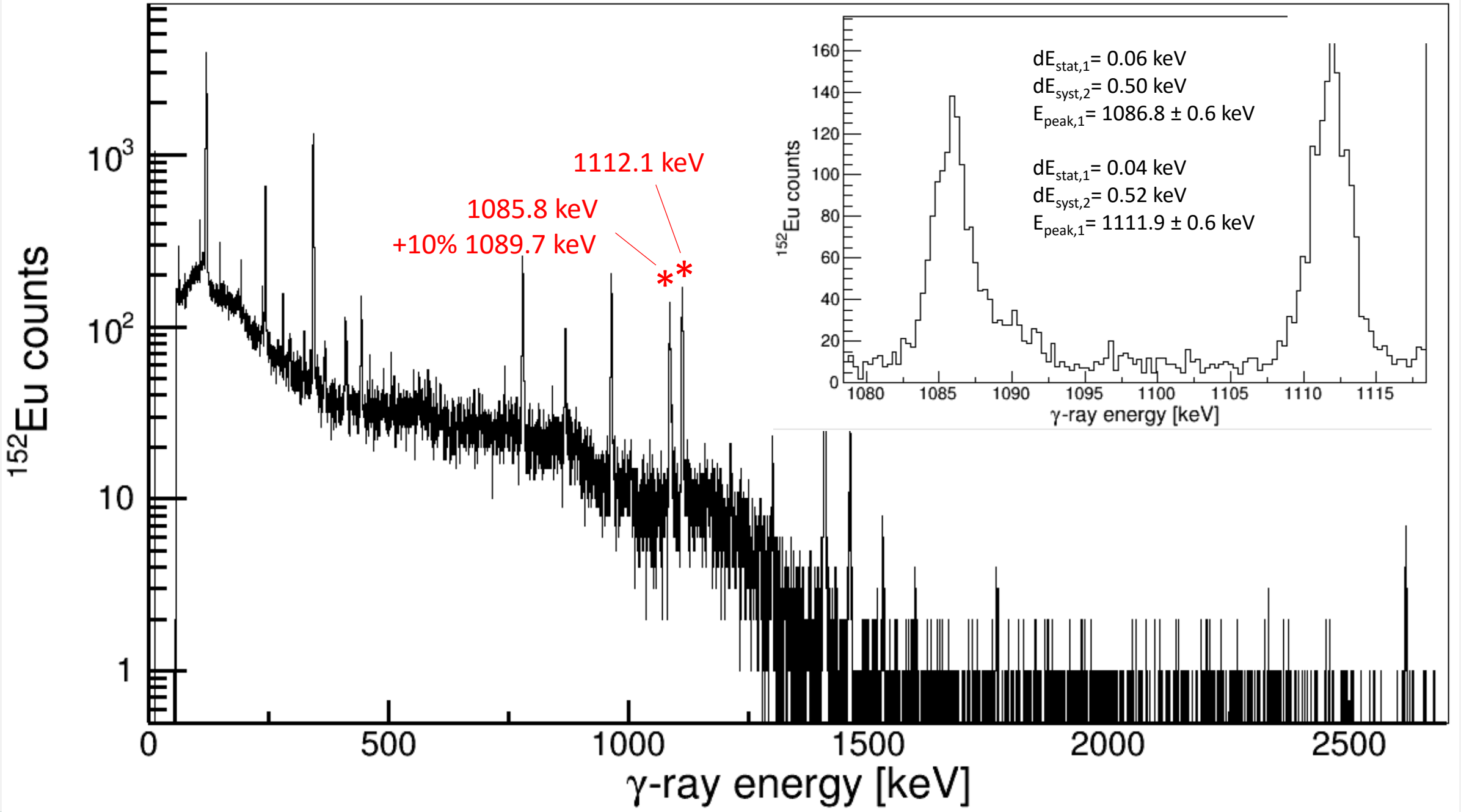
Bask in the glory of your plot




*121.8 keV
27693 counts in the peak
-->dE_stat= 0.01keV
dE_syst= 0.16 keV
E_peak= 121.3 ± 0.2 keV
See Lecture 1 slides & this presentation for info on uncertainty calculation
Mean 121.3
RMS 1.356
152Eu counts
γ-ray energy [keV]
152Eu counts
γ-ray energy [keV]


1112.1 keV
1085.8 keV
+10% 1089.7 keV
**
^{152}Eu counts
γ-ray energy [keV]
$dE_{stat,1}$= 0.06 keV
$dE_{syst,2}$= 0.50 keV
$E_{peak,1}$= 1086.8 ± 0.6 keV
$dE_{stat,1}$= 0.04 keV
$dE_{syst,2}$= 0.52 keV
$E_{peak,1}$= 1111.9 ± 0.6 keV

Assignment

- Plot 2 more ^{152}Eu peaks and compare to the accepted value, including uncertainty.
  - Hand-in the plots (publication-quality) along with the energy-comparison
- Run-plan/preparatory notes for your experiment
  - Keep in mind that these notes should serve as useful time-savers for your in the lab.
  - E.g. Order of operations, useful calculations, citations to relevant publications/book chapters