

## Intro Root and statistics



July 17<sup>th</sup> 2014  
MH17 plane crash

*298 people died  
(193 Dutch)*

HASCO school is more than just learning  
about the Standard Model

International collaboration and research  
is not about politics. On the contrary





This does NOT mean that I like this!

on the contrary!

# Computing at HASCO school

## Intro Root / statistics



Ivo van Vulpen  
(Amsterdam)

## Data preparation



Riccardo Di Sipio  
(Bologna)

### **Friday 25/7**

- 11:00-12:30 Lecture
- 16:30-18:30 Hands-on

### **Monday 28/7**

- 11:30-12:30 Lecture
- 14:00-16:00 Hands-on



# Computing at HASCO school

Intro Root / statistics



Ivo van Vulpen  
(Amsterdam)

## **Lecturer at university of Amsterdam**

Introduction Python programming

Particle physics (bachelor)

Higgs (master/PhD)

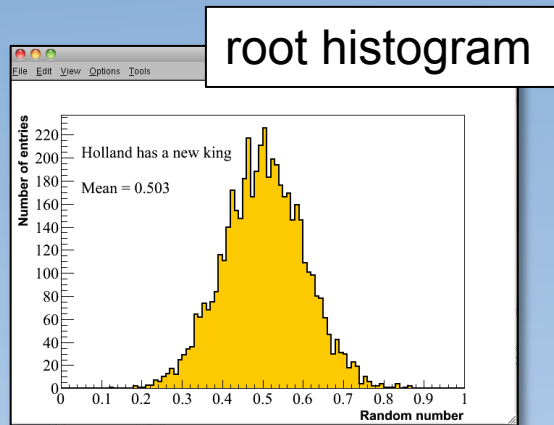
## **Researcher at Nikhef**

ATLAS (Higgs physics)

# Goals for today

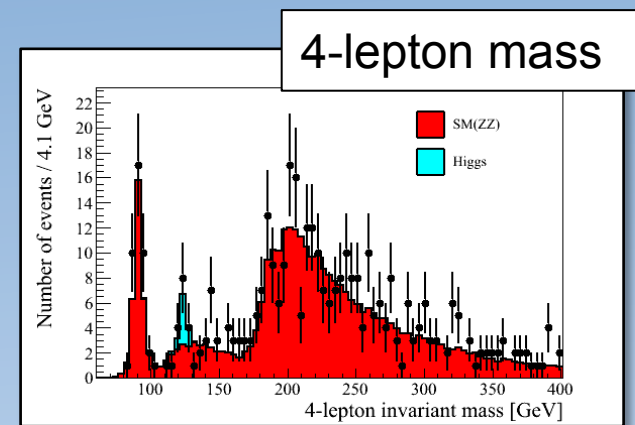
Note: background in computing for HASCO students is VERY different

## [A] Root and data manipulation



- 1) Manipulate histograms from a root file
- 2) Write and compile your own Root macro

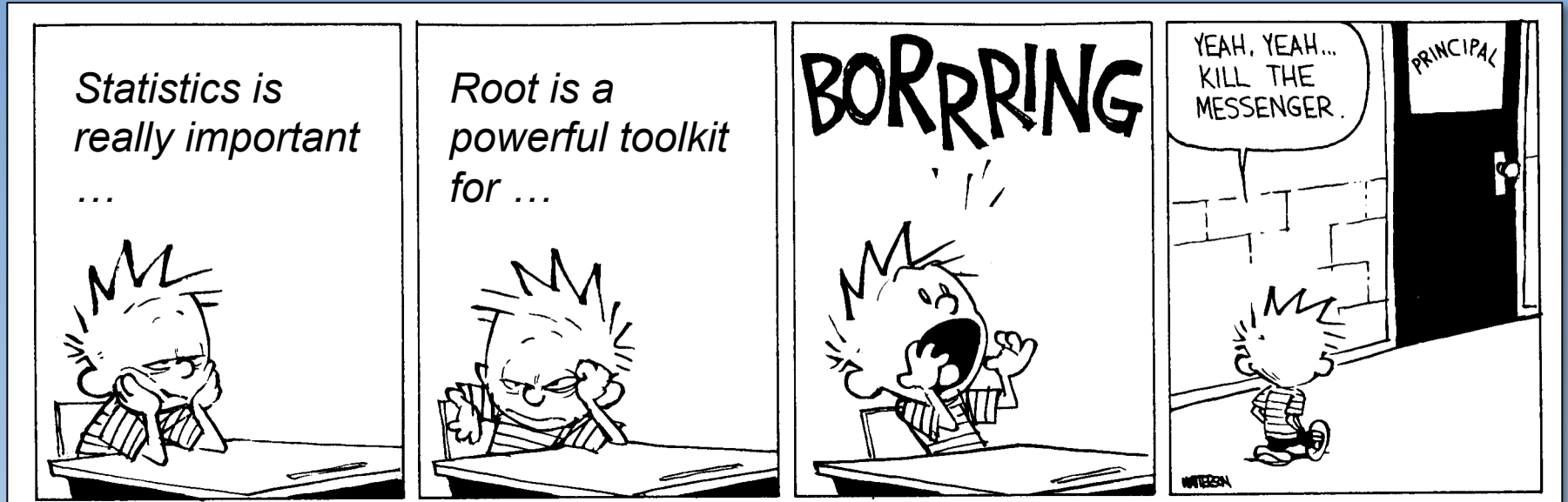
## [B] Statistics and data analysis



- 1) Do a likelihood fit yourself  
bkg. estimation in signal region
- 2) Definition of significance  
optimize a search window

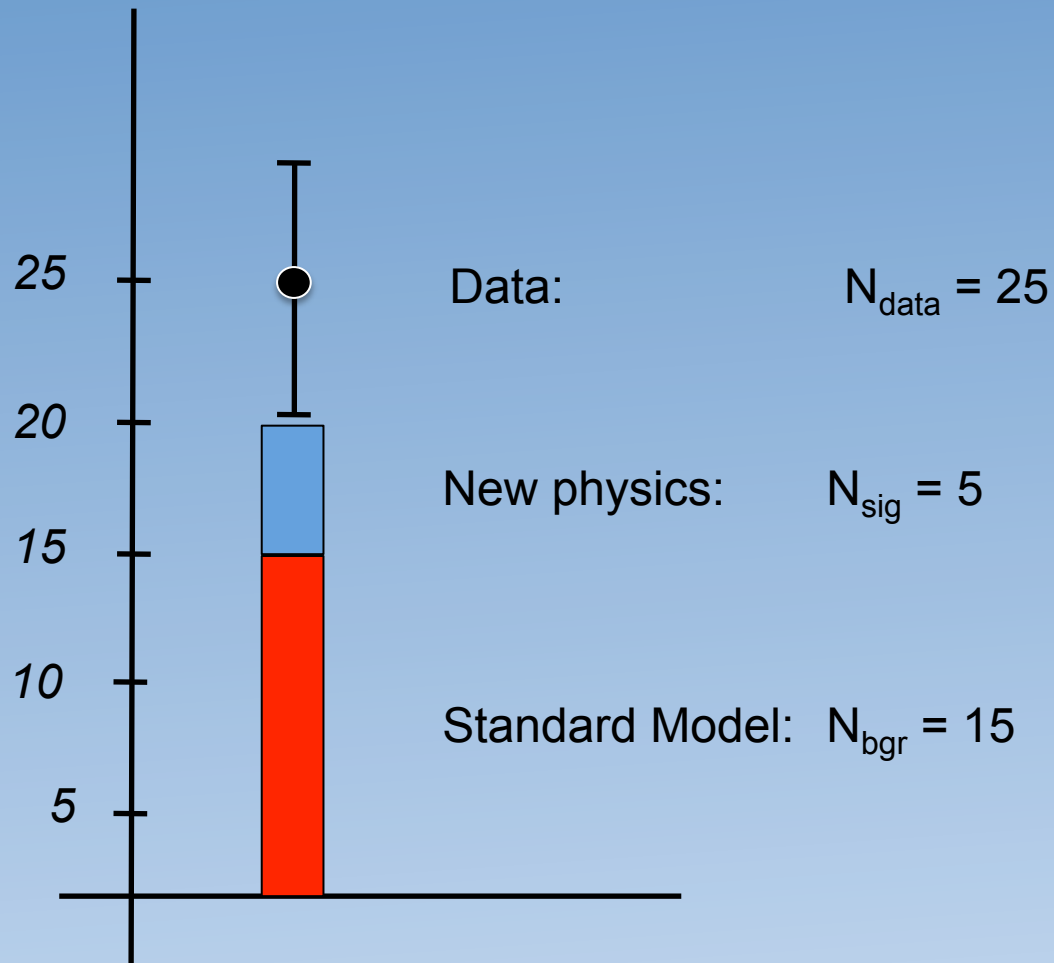


# A short lecture on Root and statistics



Note: will be 95% of your work. Master this and you can focus on physics

## Example of 'simple' statistics



*What is the significance ?*



# Statistics is everywhere in science and industry

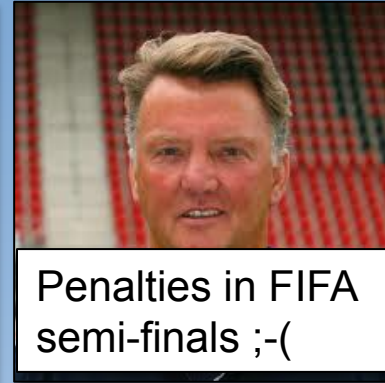
Risk analyses



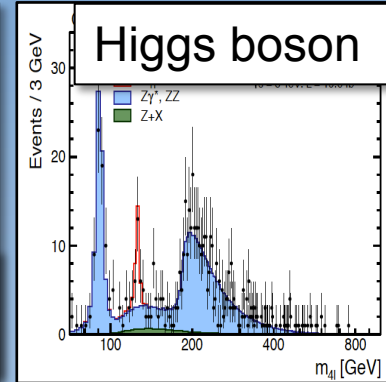
Banking/consultancy



Penalties in FIFA semi-finals ;-(



Higgs boson



- Many mysteries, folklore, buzz-words, bluffing etc.
  - **you** need to master it to summarize your analysis
  - do **not** just 'do what everybody else / your supervisor does'
- RooFit, BAT, TMVA, BDT's are excellent and very powerful tools  
Understand the basics → **then** ask RooFit to do complex stuff

“Do the basics yourself at least once”

Results from any scientific or business study:

$$\text{Result} = X \pm \Delta X$$



Particle mass, cross-section, excluded cross-section, numerical integral, probability of bankruptcy ... or becoming a millionair

Make sure you know how you extracted this



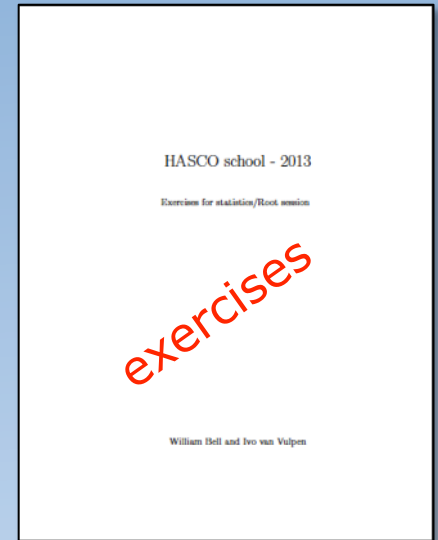
# Root/Statistics sessions

Goal: 1) have you learn Root basics and manipulate histogram data  
2) do a Likelihood fit and extract a number and it's error  
3) understand what a significance is

## Friday:

Lecture 1: Introduction to Root and statistics-exercises

Exercises: Hands-on computing exercises



Note: - exam questions will cover Root/statistic concepts (i.e. no coding)  
- if you do not know any C++ or are a Root-expert already let me know

# Basic material for the Root examples:

- 1) Download tarball: **HascoRootStatisticsCode.tgz**
- 2) Unpack everything: **tar -vzxf HascoRootStatisticsCode.tgz**

## Directory /RootExamples/

- |   |                                    |
|---|------------------------------------|
| a) Example0*.C (* = 0,1,2,3,4,5)          | All *.C-files in this presentation |
| b) Code for Ntuple production and reading |                                    |
| c) rootlogon.C                            | some standard Root settings        |

## Directory /Exercises/

- a) Histograms\_fake.root  
4 histograms of the 4-lepton invariant mass (H125, H200, ZZ, data)
- b) Hasco\_skeleton.C  
skeleton code (different levels, as minimal as possible). Your code !
- c) rootlogon.C  
some standard Root settings



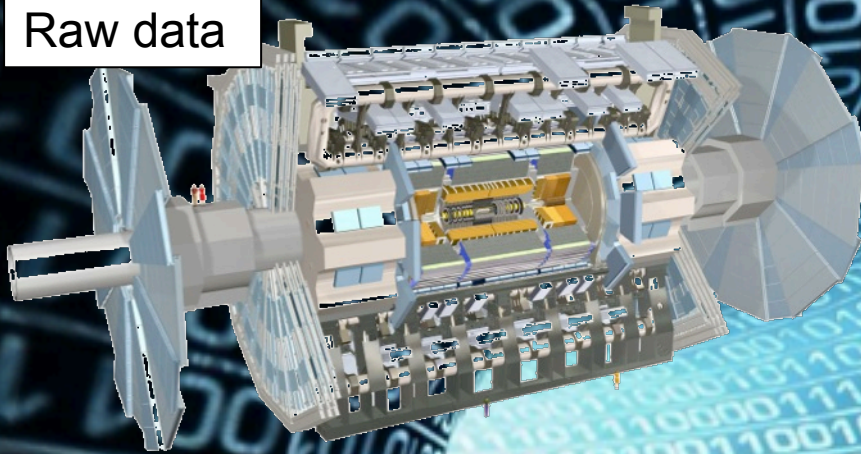
# Root

Don't worry when you do not know C++ or Root already

... well ok, worry a bit, but not too much

ATLAS experiment: per second: 40.000.000 x 20 x 1 Mbyte

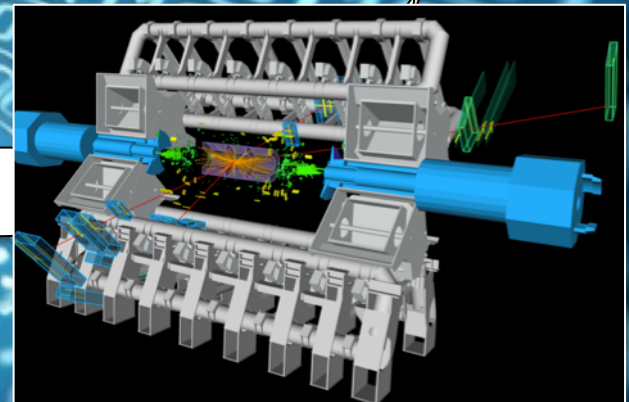
Raw data



15 Pbytes of data

Objects: electrons, muons, tracks, clusters, ...

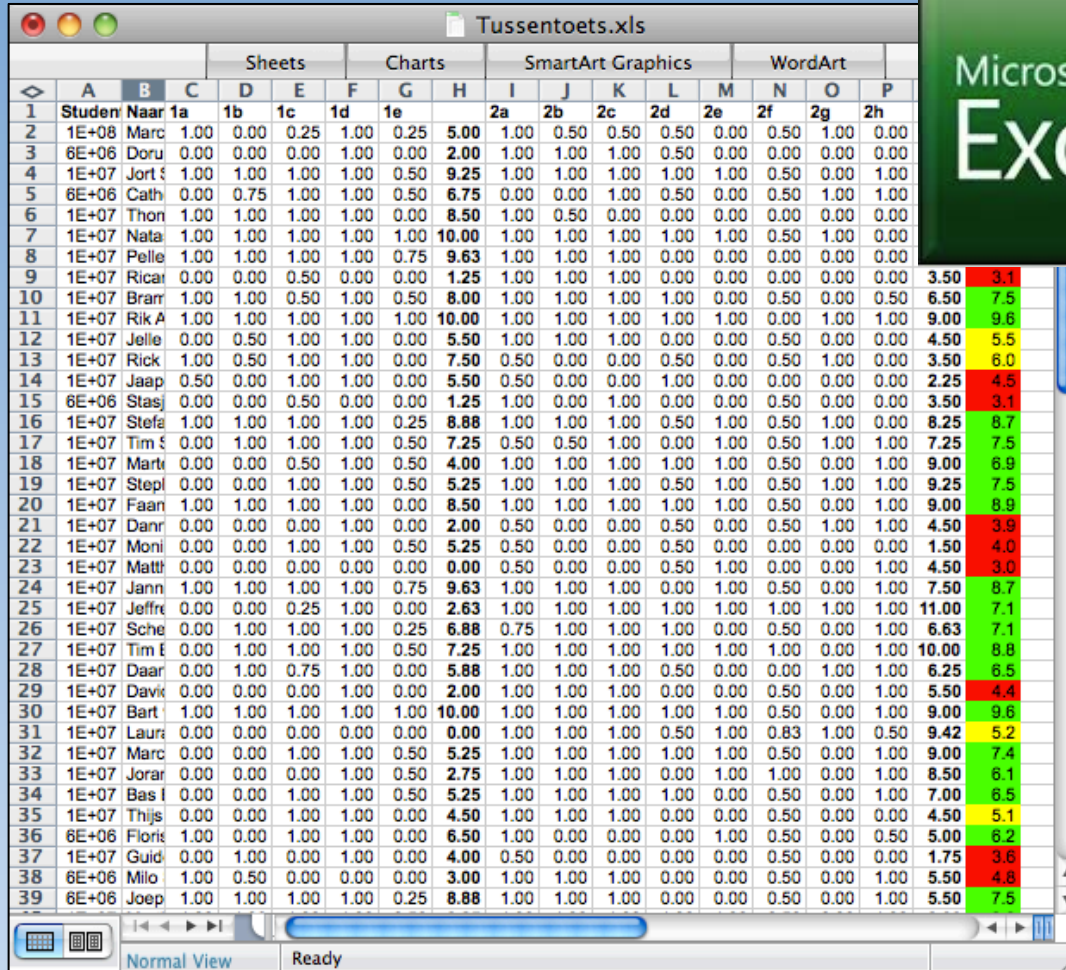
Event display



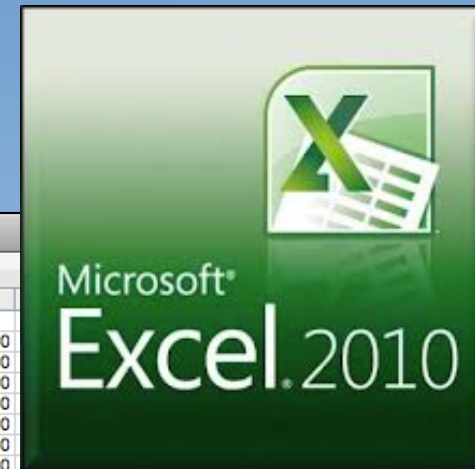
Ntuples: final end-stage analysis



# Excel or ascii files will not do



	Sheets				Charts				SmartArt Graphics				WordArt			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Student	Naam	1a	1b	1c	1d	1e		2a	2b	2c	2d	2e	2f	2g	2h
2	1E+08	Marc	1.00	0.00	0.25	1.00	0.25	5.00	1.00	0.50	0.50	0.50	0.00	0.50	1.00	0.00
3	6E+06	Doru	0.00	0.00	0.00	1.00	0.00	2.00	1.00	1.00	1.00	0.50	0.00	0.00	0.00	0.00
4	1E+07	Jort	1.00	1.00	1.00	1.00	0.50	9.25	1.00	1.00	1.00	1.00	1.00	0.50	0.00	1.00
5	6E+06	Cath	0.00	0.75	1.00	1.00	0.50	6.75	0.00	0.00	1.00	0.50	0.00	0.50	1.00	1.00
6	1E+07	Thon	1.00	1.00	1.00	1.00	0.00	8.50	1.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00
7	1E+07	Nata	1.00	1.00	1.00	1.00	1.00	10.00	1.00	1.00	1.00	1.00	1.00	0.50	1.00	0.00
8	1E+07	Pelle	1.00	1.00	1.00	1.00	0.75	9.63	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00
9	1E+07	Rica	0.00	0.00	0.50	0.00	0.00	1.25	1.00	1.00	1.00	0.00	0.00	0.00	0.00	3.50
10	1E+07	Brann	1.00	1.00	0.50	1.00	0.50	8.00	1.00	1.00	1.00	1.00	0.00	0.50	0.00	6.50
11	1E+07	Rik A	1.00	1.00	1.00	1.00	1.00	10.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	9.00
12	1E+07	Jelle	0.00	0.50	1.00	1.00	0.00	5.50	1.00	1.00	1.00	0.00	0.00	0.50	0.00	4.50
13	1E+07	Rick	1.00	0.50	1.00	1.00	0.00	7.50	0.50	0.00	0.00	0.50	0.00	0.50	1.00	3.50
14	1E+07	Jaap	0.50	0.00	1.00	1.00	0.00	5.50	0.50	0.00	0.00	1.00	0.00	0.00	0.00	2.25
15	6E+06	Stas	0.00	0.00	0.50	0.00	0.00	1.25	1.00	0.00	1.00	0.00	0.00	0.50	0.00	3.50
16	1E+07	Stefa	1.00	1.00	1.00	1.00	0.25	8.88	1.00	1.00	1.00	0.50	1.00	0.50	1.00	8.25
17	1E+07	Tim	0.00	1.00	1.00	1.00	0.50	7.25	0.50	0.50	1.00	0.00	1.00	0.50	1.00	7.25
18	1E+07	Mart	0.00	0.00	0.50	1.00	0.50	4.00	1.00	1.00	1.00	1.00	1.00	0.50	0.00	9.00
19	1E+07	Steph	0.00	0.00	1.00	1.00	0.50	5.25	1.00	1.00	1.00	0.50	1.00	0.50	1.00	9.25
20	1E+07	Faan	1.00	1.00	1.00	1.00	0.00	8.50	1.00	1.00	1.00	1.00	1.00	0.50	0.00	9.00
21	1E+07	Dann	0.00	0.00	0.00	1.00	0.00	2.00	0.50	0.00	0.00	0.50	0.00	0.50	1.00	4.50
22	1E+07	Moni	0.00	0.00	1.00	1.00	0.50	5.25	0.50	0.00	0.00	0.50	0.00	0.00	0.00	1.50
23	1E+07	Matth	0.00	0.00	0.00	0.00	0.00	0.00	0.50	0.00	0.00	0.50	1.00	0.00	0.00	4.50
24	1E+07	Jann	1.00	1.00	1.00	1.00	0.75	9.63	1.00	1.00	1.00	0.00	1.00	0.50	0.00	7.50
25	1E+07	Jeffre	0.00	0.00	0.25	1.00	0.00	2.63	1.00	1.00	1.00	1.00	1.00	1.00	1.00	11.00
26	1E+07	Sche	0.00	1.00	1.00	1.00	0.25	6.88	0.75	1.00	1.00	1.00	0.00	0.50	0.00	6.63
27	1E+07	Tim	0.00	1.00	1.00	1.00	0.50	7.25	1.00	1.00	1.00	1.00	1.00	1.00	0.00	10.00
28	1E+07	Daar	0.00	1.00	0.75	1.00	0.00	5.88	1.00	1.00	1.00	0.50	0.00	0.00	1.00	6.25
29	1E+07	Davie	0.00	0.00	0.00	1.00	0.00	2.00	1.00	1.00	1.00	0.00	0.00	0.50	0.00	5.50
30	1E+07	Bart	1.00	1.00	1.00	1.00	1.00	10.00	1.00	1.00	1.00	1.00	1.00	0.50	0.00	9.00
31	1E+07	Lauri	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	0.50	1.00	0.83	1.00	9.42
32	1E+07	Marc	0.00	0.00	1.00	1.00	0.50	5.25	1.00	1.00	1.00	1.00	1.00	0.50	0.00	9.00
33	1E+07	Joran	0.00	0.00	0.00	1.00	0.50	2.75	1.00	1.00	1.00	0.00	1.00	1.00	0.00	8.50
34	1E+07	Bas	0.00	0.00	1.00	1.00	0.50	5.25	1.00	1.00	1.00	1.00	0.00	0.50	1.00	7.00
35	1E+07	Thijs	0.00	0.00	1.00	1.00	0.00	4.50	1.00	1.00	1.00	0.00	0.00	0.50	0.00	4.50
36	6E+06	Flori	1.00	0.00	1.00	1.00	0.00	6.50	1.00	0.00	0.00	0.00	1.00	0.50	0.00	5.00
37	1E+07	Guid	0.00	1.00	0.00	1.00	0.00	4.00	0.50	0.00	0.00	0.00	0.00	0.50	0.00	1.75
38	6E+06	Milo	1.00	0.50	0.00	0.00	0.00	3.00	1.00	1.00	1.00	0.00	0.00	0.50	0.00	5.50
39	6E+06	Joep	1.00	1.00	1.00	1.00	0.25	8.88	1.00	1.00	1.00	0.00	0.00	0.50	0.00	5.50





# ROOT

An Object-Oriented  
Data Analysis Framework





<http://root.cern.ch>



The screenshot shows the ROOT website homepage. At the top, there's a navigation bar with links: Home, What's New, About, Screenshots, Download, Documentation, Support, Forum, and Developers. Below this, there are three main sections: Screenshots, Download, and Documentation, each with an icon and a brief description. The Documentation section is highlighted with a box. Below these sections, there's a 'What's New' section with a list of recent updates, a 'Recent Blog Posts' section, and a 'Follow Us On' section with a Twitter link. The main content area features a large announcement for the 'ROOT Users Workshop, 11 - 14 March, Saas-Fee', featuring ROOT 6 - The Next Generation. It includes details about the workshop, a list of topics, and a link to the workshop poster. Below this, there's a 'Patch release 5.34/09' section and a 'ROOT has moved to Git' section.

User guide  
(630 pages)



Howto's



Tutorials

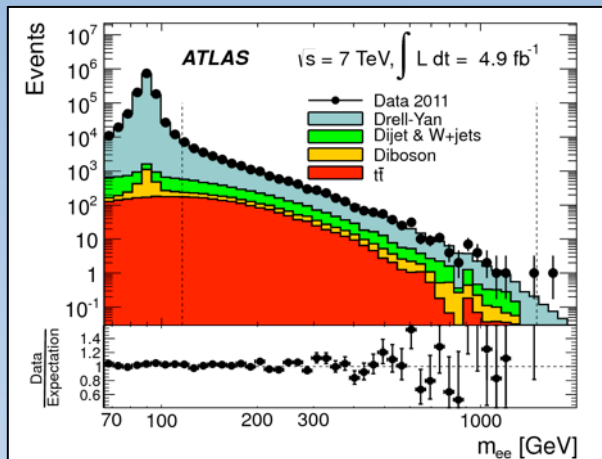


# Root:

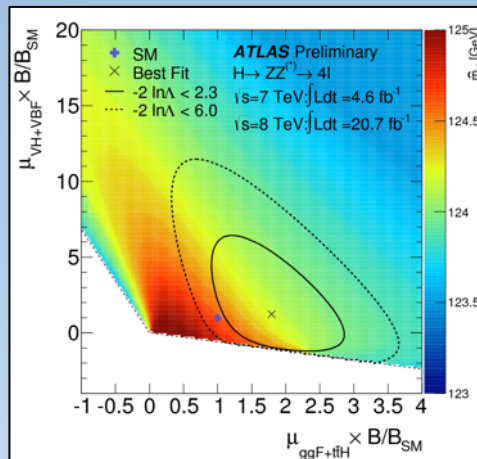
- |                    |   |
|--------------------|---|
| [1] HEP toolkit:   | C++ based analysis framework                |
| [2] Data analysis: | storing, manipulating                       |
| [3] Modeling:      | model building, fitting, hypothesis testing |
| [4] Visualisation: | 1 to multi-dimensional                      |

## Root [4]: data visualisation

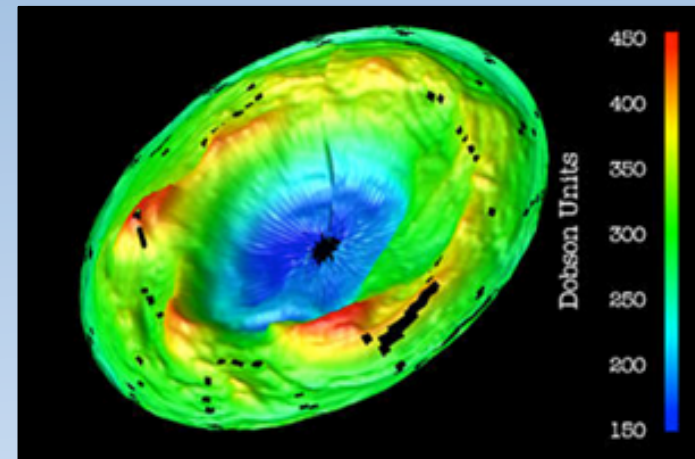
*1-dimensional*



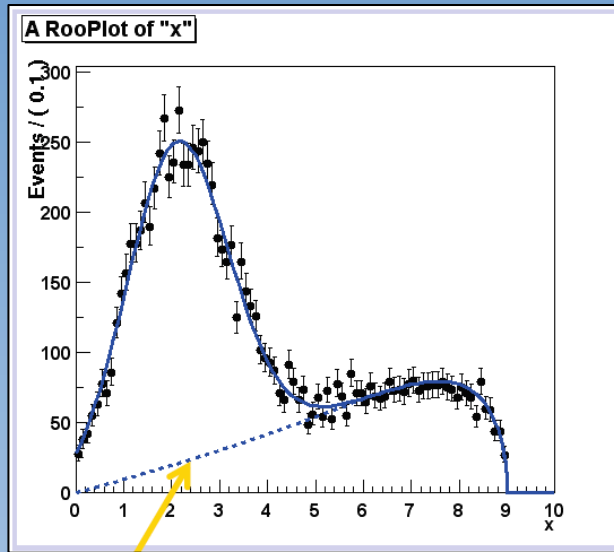
*2-dimensional*



*3-dimensional*



## Root [3]: data modeling & hypothesis testing



Modeling & (numerical) convolutions

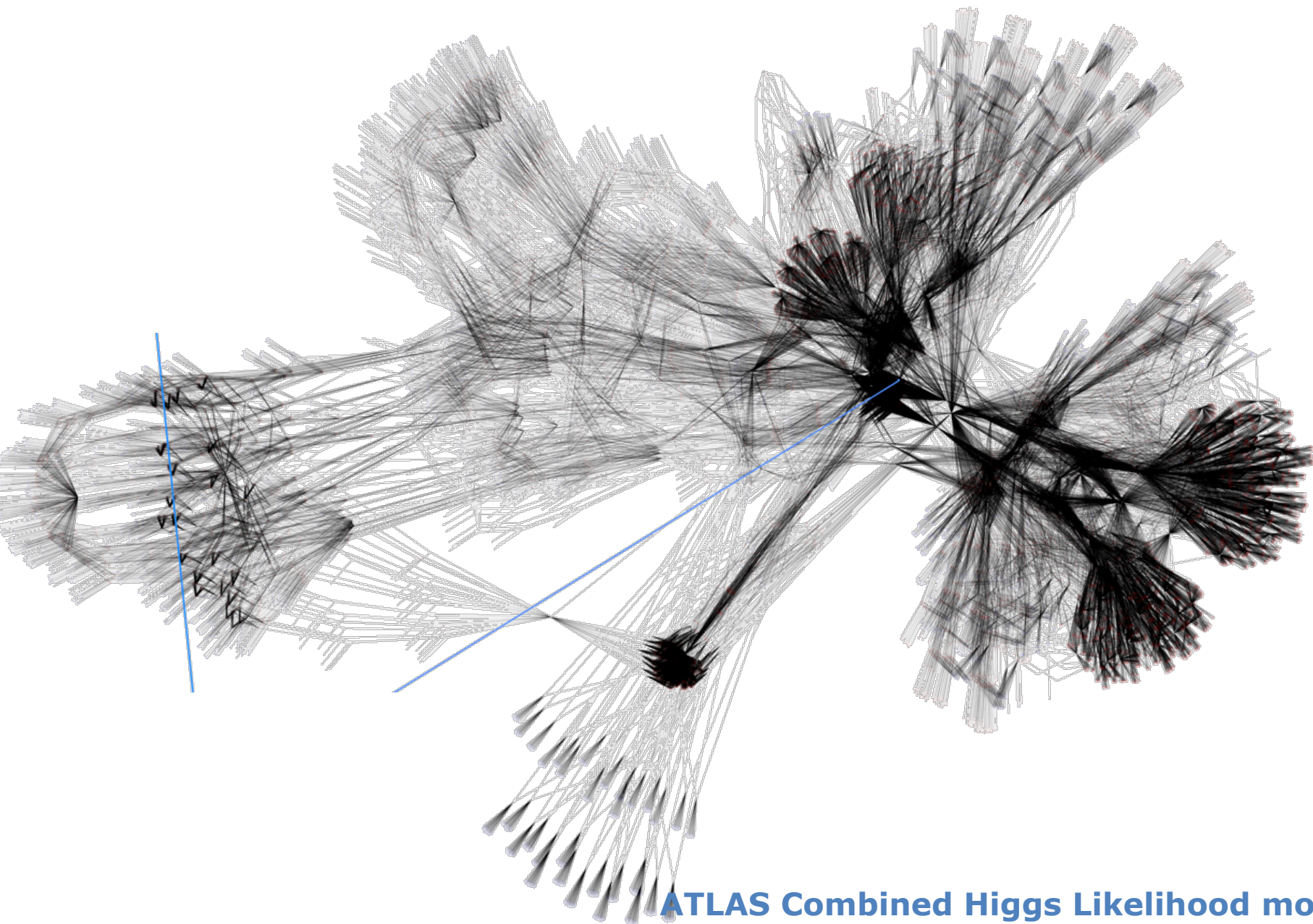
Statistics tools: Fitting, hypothesis testing, test-statistic, toy-MC, significance, limits, profiling

Multi-dimensional analyses: complex tools: Neural nets, Boosted decision trees etc.

→ **We'll do our own fit in the exercise session**

## Root [1,2]: mathematics & physics tools

- Types: int, float, double, vectors, matrices, ... but also Lorentz vectors etc.  
you can of course build your own class/object/structure
- Random numbers, matrix manipulation, PDG information, boosts
- Geant4, ...

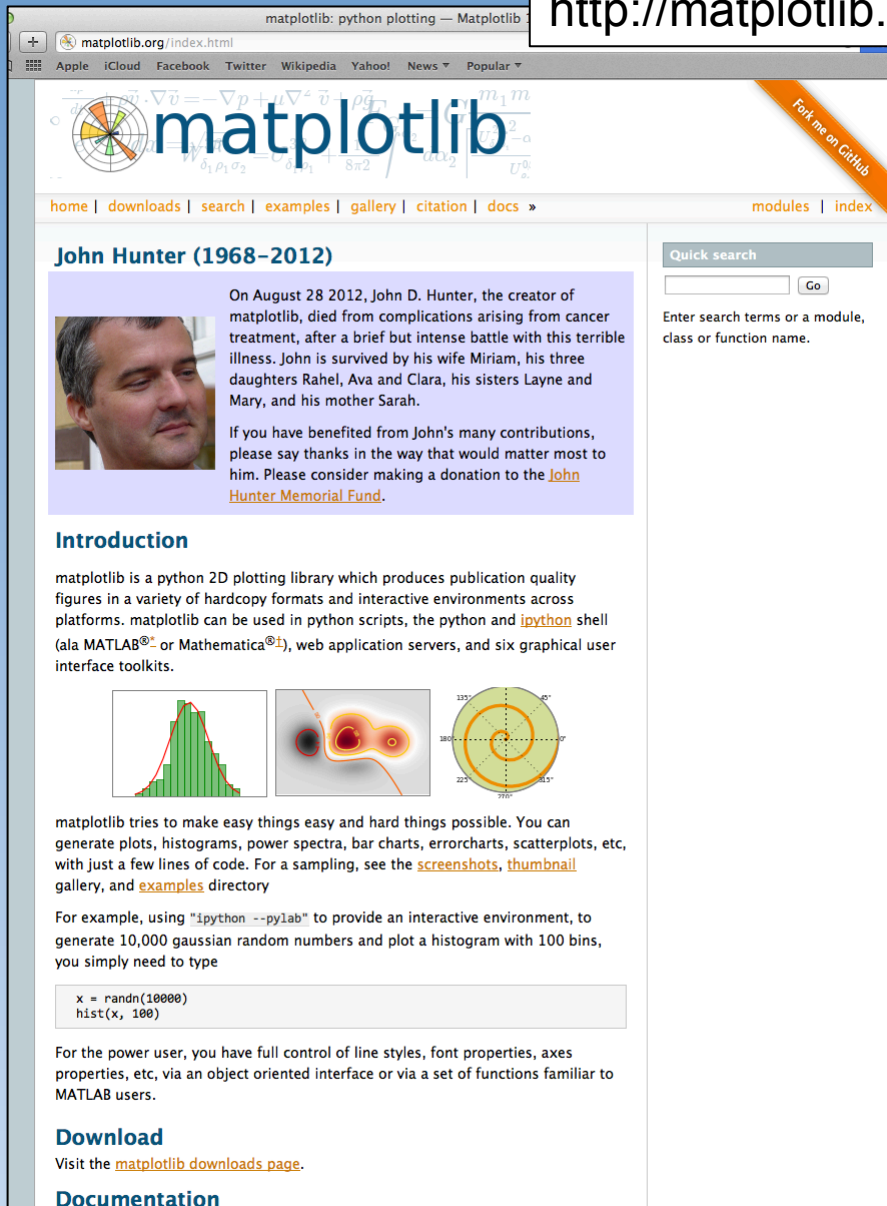


**ATLAS Combined Higgs Likelihood model  
(W. Verkerke)**



# Data analysis and visualisation in Python (Matplotlib)

<http://matplotlib.org>



The screenshot shows the matplotlib.org website. At the top, there's a navigation bar with links to home, downloads, search, examples, gallery, citation, docs, modules, and index. Below this, there's a section for John Hunter (1968-2012) with a portrait and a message. To the right of this is a quick search bar. Below the John Hunter section is an introduction to matplotlib, describing it as a python 2D plotting library. There are three small images showing different plot types: a histogram, a heatmap, and a polar plot. Below these images is a code snippet for generating a histogram. At the bottom, there's a download section and a documentation link.

matplotlib: python plotting — Matplotlib

[matplotlib.org/index.html](http://matplotlib.org/index.html)

Apple iCloud Facebook Twitter Wikipedia Yahoo! News Popular

home | downloads | search | examples | gallery | citation | docs » modules | index

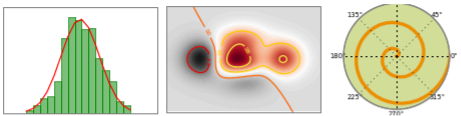
## John Hunter (1968–2012)

On August 28 2012, John D. Hunter, the creator of matplotlib, died from complications arising from cancer treatment, after a brief but intense battle with this terrible illness. John is survived by his wife Miriam, his three daughters Rahel, Ava and Clara, his sisters Layne and Mary, and his mother Sarah.

If you have benefited from John's many contributions, please say thanks in the way that would matter most to him. Please consider making a donation to the [John Hunter Memorial Fund](#).

### Introduction

matplotlib is a python 2D plotting library which produces publication quality figures in a variety of hardcopy formats and interactive environments across platforms. matplotlib can be used in python scripts, the python and [ipython](#) shell (ala MATLAB® or Mathematica®), web application servers, and six graphical user interface toolkits.



matplotlib tries to make easy things easy and hard things possible. You can generate plots, histograms, power spectra, bar charts, errorcharts, scatterplots, etc, with just a few lines of code. For a sampling, see the [screenshots](#), [thumbnail gallery](#), and [examples](#) directory

For example, using "ipython --pylab" to provide an interactive environment, to generate 10,000 gaussian random numbers and plot a histogram with 100 bins, you simply need to type

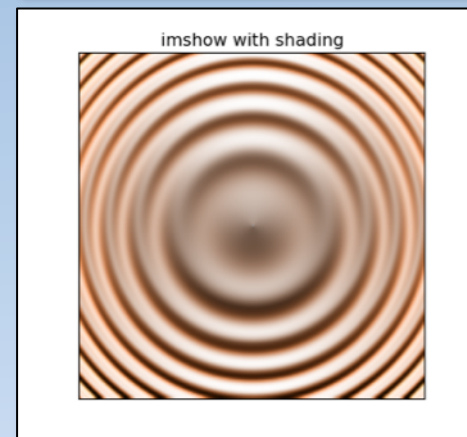
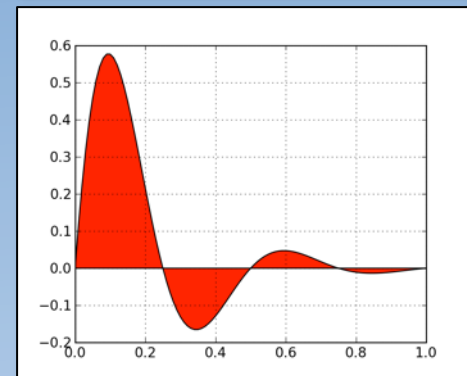
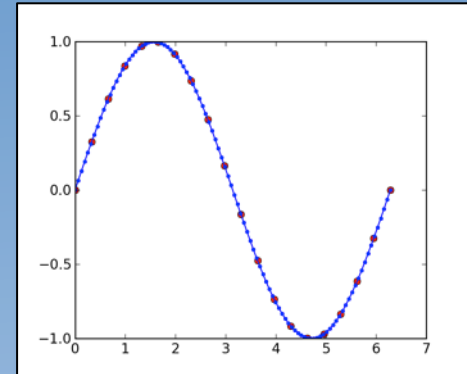
```
x = randn(10000)
hist(x, 100)
```

For the power user, you have full control of line styles, font properties, axes properties, etc, via an object oriented interface or via a set of functions familiar to MATLAB users.

### Download

Visit the [matplotlib downloads page](#).

### Documentation



<https://www.enthought.com/downloads/>

# Running your first Root macro

*This '++' 'compiles' your macro. Spot mistakes*

Editor: Example00.C

```
New Open Recent Save Print Undo Redo Cut Copy Paste Search
1 #include <iostream>
2 using namespace std;
3
4 //-----
5 void Helloworld(){
6 //-----
7
8     cout << "Welcome to the Hasco summerschool" << endl;
9
10    return;
11
12 } // end Helloworld()
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2635
2636
2637
2638
2639
2640
2641
2642
2643
2644
2645
2646
2647
2648
2649
2650
2651
2652
2653
2654
265
```

# Histograms

You'll use these during the exercise session

# Histogram\_Example\_01.C

"plot a histogram on screen"

Header file (TH1D)

Editor

```
1 #include "TH1D.h"
2
3 //-----
4 void Histogram_Example_01(){
5 //-----
6
7 //-- Book the histogram
8 TH1D *hist = new TH1D("hist", "My dummy histogram", 10,0.,1.);
9
10 //-- Fill two bins
11 hist->SetBinContent(4,2.);
12 hist->SetBinContent(7,1.);
13
14 //-- Draw the histogram
15 hist->Draw();
16
17 return;
18
19 } // end Histogram_example_01()
20
```

Book a histogram  
10 bins between 0 and 1

Fill histogram

Draw histogram

Unix shell

```
bash-3.2$
bash-3.2$
bash-3.2$ root -l

Standard RootLogon

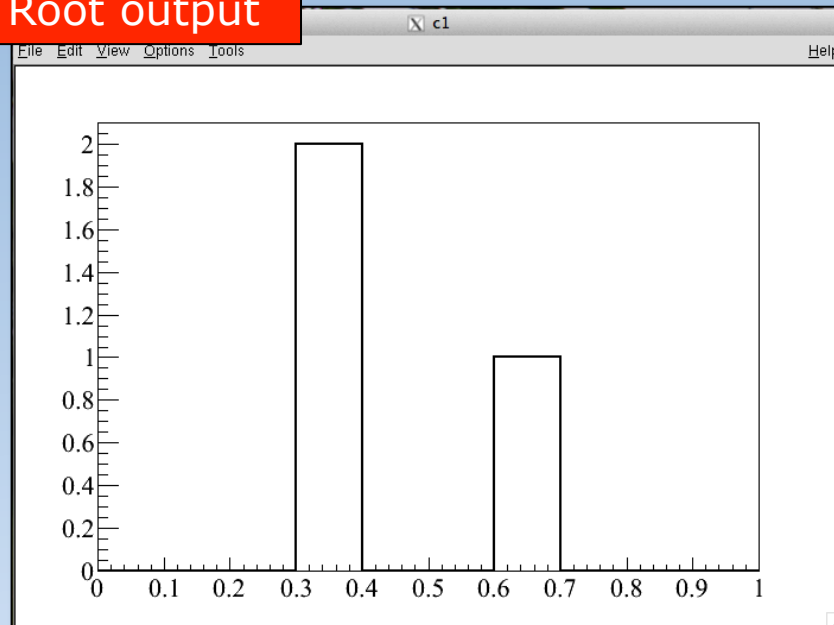
root [0] .L Example01.C++
Info in <TUnixSystem::LoadLibrary>:
07_HASC0/code/./Example01.C.so
root [1]
root [1] Histogram_Example_01
Info in <TCanvas::MakeDefaultCanvas>: created default TCanvas with name c1
root [2]
```

Start Root  
Unix> root -l

Compile macro  
Root> .L Example01.C++

Run a routine in the macro  
Root> Histogram\_Example\_01()

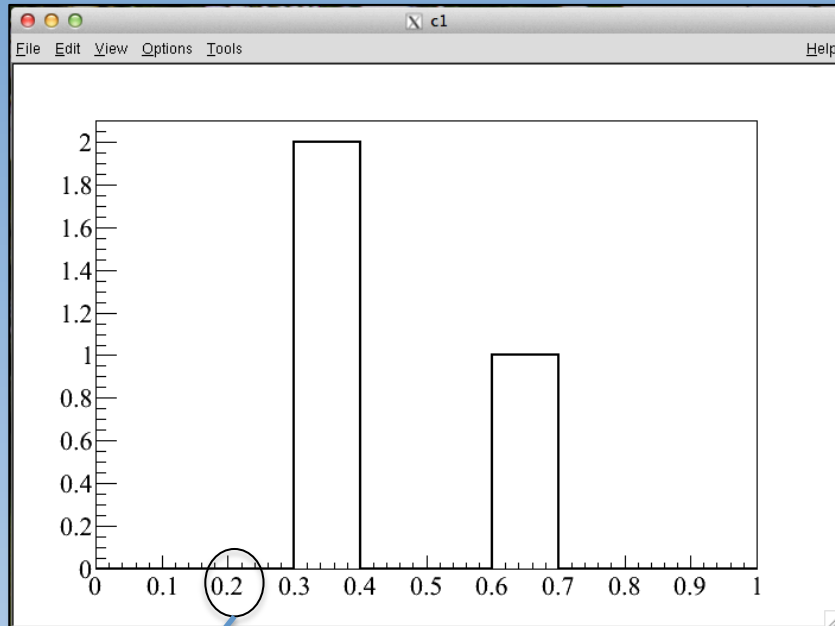
Root output



# Inspect and style histograms

## TH1:

<http://root.cern.ch/root/html/TH1.html>



## Details:

```
hist->SetLabelColor()  
hist->SetLabelFont()  
hist->SetLabelOffset()  
hist->SetLabelSize()
```

*You'll need these  
in the exercises*

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

## Style:

```
hist->SetFillColor(i_color)  
hist->SetFillStyle()  
hist->SetLineColor()  
hist->SetLineStyle()  
hist->SetLineWidth
```

...

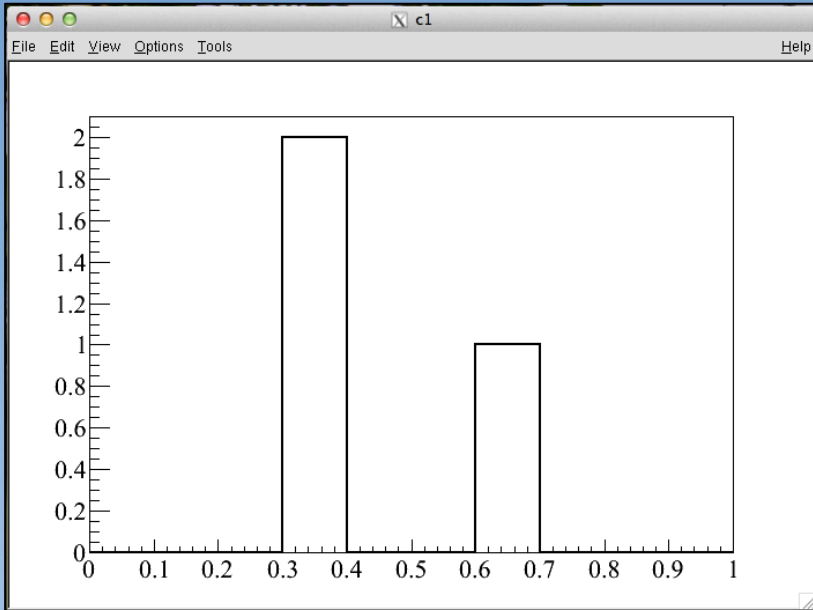
## Inspect:

```
hist->GetRMS()  
hist->GetMean()  
hist->GetSumOfWeights()  
hist->GetMaximumBin()  
hist->GetBinContent(i_bin)  
hist->GetBinCenter(i_bin)  
hist->Integrate(...)  
hist->Write(...)
```

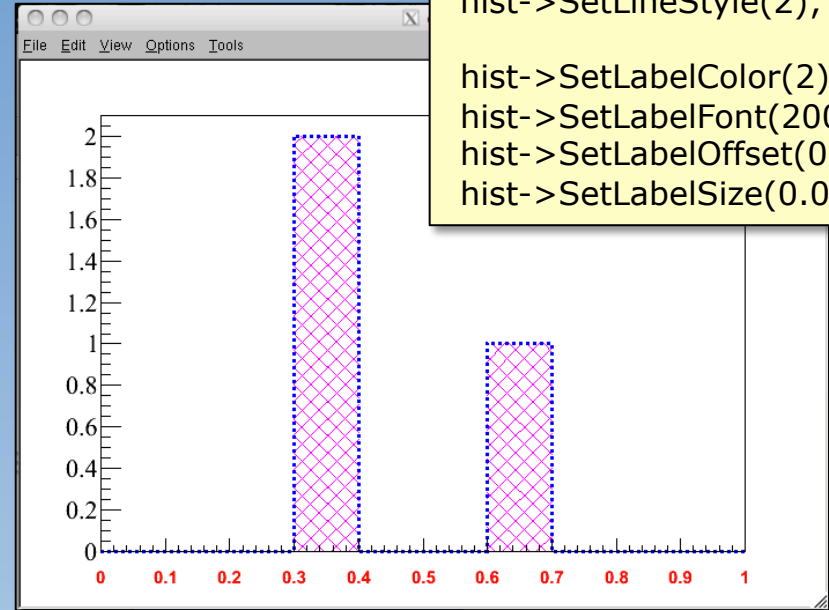
...



## Standard



## Your style



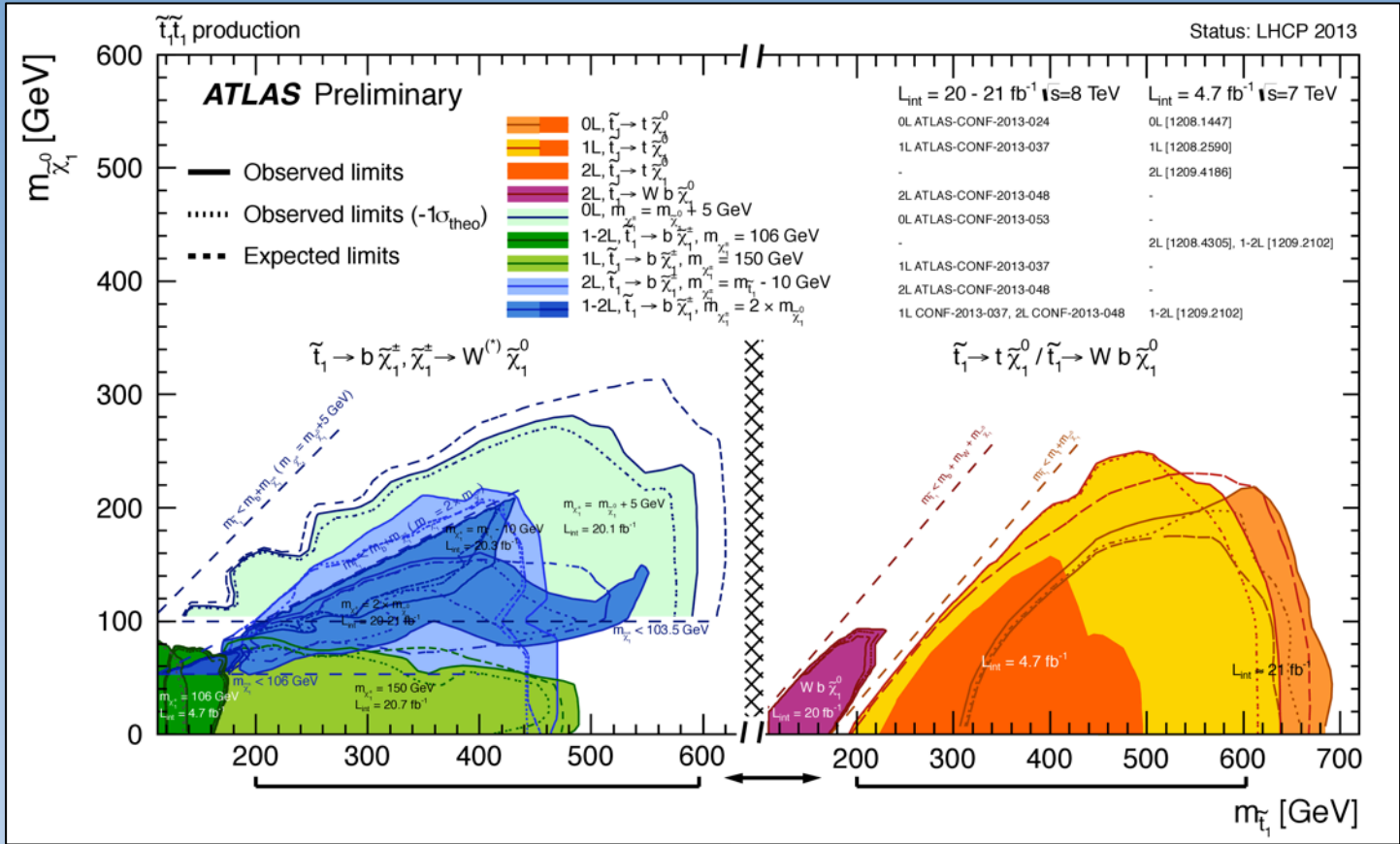
```
hist->SetFillColor(6);  
hist->SetFillStyle(3544);
```

```
hist->SetLineColor(4);  
hist->SetLineWidth(3);  
hist->SetLineStyle(2);
```

```
hist->SetLabelColor(2);  
hist->SetLabelFont(200);  
hist->SetLabelOffset(0.03);  
hist->SetLabelSize(0.035);
```

- Note:
- beauty is in the eye of the beholder
  - take some time to make the plot clear
  - default settings in rootlogon.C

Summarizing your measurement is important ...  
and not easy

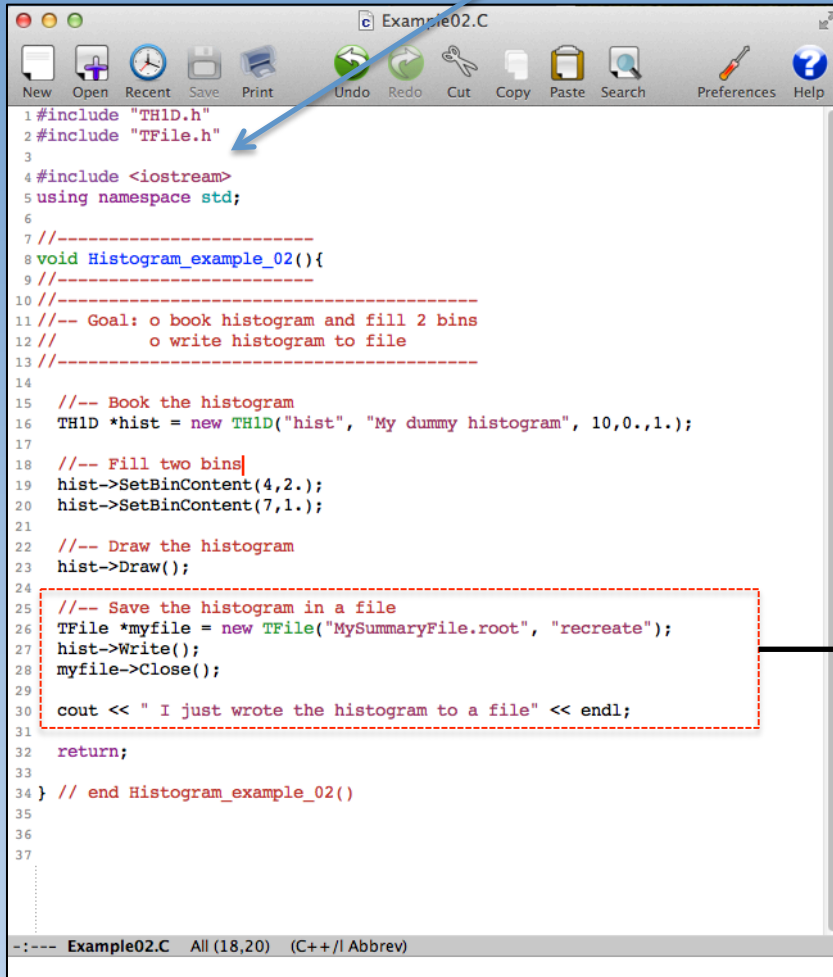


Tip: analysis takes  $O(1 \text{ year})$ . Take  $> 1$  minute for final plot

# Histogram\_Example\_02.C

"write histogram to file"

TFile



```
1 #include "TH1D.h"
2 #include "TFile.h"
3
4 #include <iostream>
5 using namespace std;
6
7 //-----
8 void Histogram_example_02(){
9 //-----
10 //-----
11 //-- Goal: o book histogram and fill 2 bins
12 //          o write histogram to file
13 //-----
14
15 //-- Book the histogram
16 TH1D *hist = new TH1D("hist", "My dummy histogram", 10,0.,1.);
17
18 //-- Fill two bins
19 hist->SetBinContent(4,2.);
20 hist->SetBinContent(7,1.);
21
22 //-- Draw the histogram
23 hist->Draw();
24
25 //-- Save the histogram in a file
26 TFile *myfile = new TFile("MySummaryFile.root", "recreate");
27 hist->Write();
28 myfile->Close();
29
30 cout << " I just wrote the histogram to a file" << endl;
31
32 return;
33
34 } // end Histogram_example_02()
35
36
37
38
39
40
41
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46
47
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49
50
51
52
53
54
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72
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75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
```

**TFile:**

<http://root.cern.ch/root/html/TFile.html>

*open a file called  
MySummaryFile.root, write  
histogram to it and close the file*

# Histogram\_Example\_03.C

"read a histogram from a file and plot it"

Unix> root -l MySummaryfile.root

option 1: command line

```
bash-3.2$ root -l MySummaryFile.root

Standard RootLogon

root [0]
Attaching file MySummaryFile.root as _file0...
root [1] .ls
TFile**      MySummaryFile.root
TFile*       MySummaryFile.root
KEY: TH1D    hist::1 My dummy histogram
root [2] hist->Draw
Info in <TCanvas::MakeDefCanvas>: created default TCanvas with name c1
root [3]
```

Root[1] .ls (like unix "ls")

Draw hist object (type TH1D)  
Root > hist->Draw()

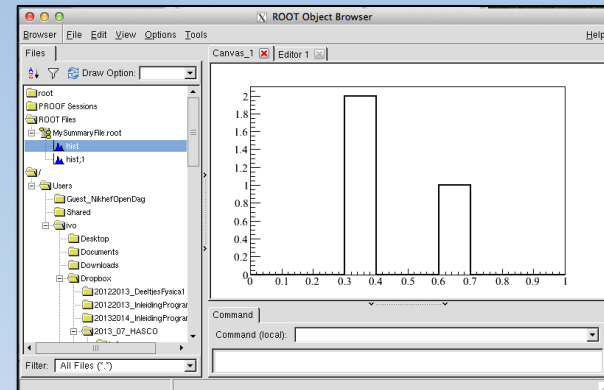
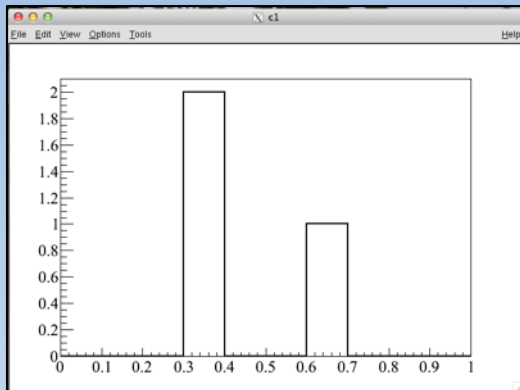
option 2: browser / clicking

```
bash-3.2$ root -l MySummaryFile.root

Standard RootLogon

root [0]
Attaching file MySummaryFile.root as _file0...
root [1] .ls
TFile**      MySummaryFile.root
TFile*       MySummaryFile.root
KEY: TH1D    hist::1 My dummy histogram
root [2] hist->Draw
Info in <TCanvas::MakeDefCanvas>: created default TCanvas with name c1
root [3] Tbrowser tb
root [4]
```

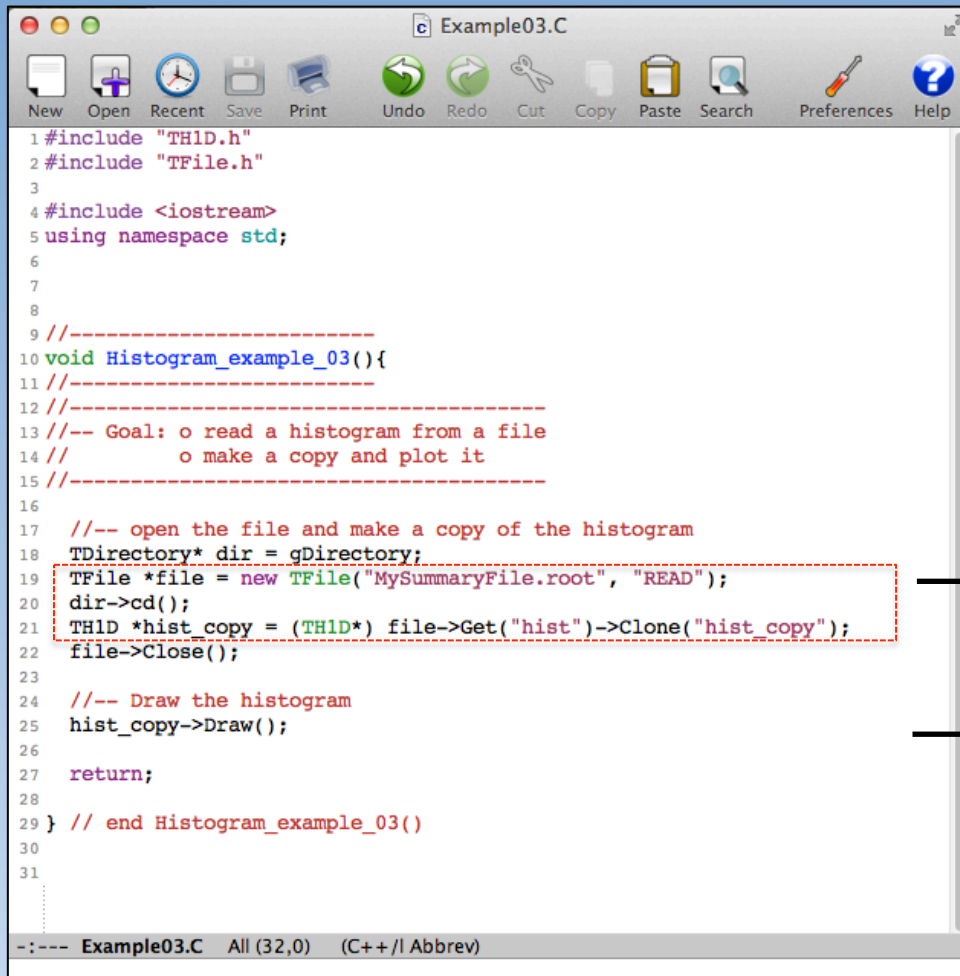
start a browser (Tbrowser)  
Root > Tbrowser tb



# Histogram\_Example\_03.C

"read a histogram from a file and plot it"

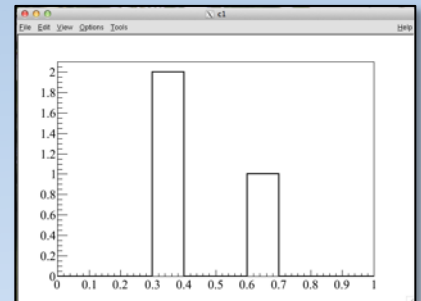
option 3: using a macro



```
1 #include "TH1D.h"
2 #include "TFile.h"
3
4 #include <iostream>
5 using namespace std;
6
7
8
9 //-----
10 void Histogram_example_03(){
11 //-----
12 //-----
13 //-- Goal: o read a histogram from a file
14 //          o make a copy and plot it
15 //-----
16
17 //-- open the file and make a copy of the histogram
18 TDirectory* dir = gDirectory;
19 TFile *file = new TFile("MySummaryFile.root", "READ");
20 dir->cd();
21 TH1D *hist_copy = (TH1D*) file->Get("hist")->Clone("hist_copy");
22 file->Close();
23
24 //-- Draw the histogram
25 hist_copy->Draw();
26
27 return;
28
29 } // end Histogram_example_03()
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
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80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
```

open the root file &  
make a copy of the histogram

draw histogram



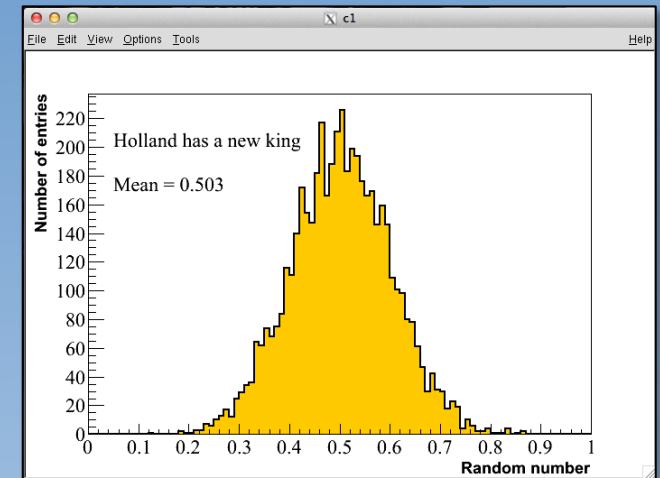


# Histogram\_Example\_04.C

"Fill histogram with random numbers and add some text"

```
Example04.C
New Open Recent Save Print Undo Redo Cut Copy Paste Search Preferences Help

1 #include "TH1D.h"
2 #include "TColor.h"
3 #include "TLatex.h"
4 #include "TRandom3.h"
5
6 //-----
7 void Histogram_example_04(int Nrandom = 5000){
8 //-----
9 //-----
10 --- Goal: o Fill a histogram with <Nrandom> numbers
11 --- o plot it and add some information
12 ---
13
14 --- book histogram (100 bins between 0. and 1.)
15 TH1D *hist = new TH1D("hist", "My dummy histogram", 100,0.,1.);
16
17 --- fill the histogram with Nrandom random numbers
18 TRandom3 *R = new TRandom3();
19 for(int i_random = 0; i_random < Nrandom; i_random++){
20     double random_number = R->Gaus(0.5,0.1); // random number: center at 0.5 and sigma = 0.1
21     hist->Fill(random_number);
22 }
23
24 --- make histogram orange and draw it
25 hist->SetFillColor(kOrange);
26 hist->Draw();
27
28 --- add axes
29 hist->SetTitle("Random number");
30 hist->SetYTitle("Number of entries");
31
32 --- add some text
33 TLatex *text1 = new TLatex(0.05,200., "Holland has a new king");
34 text1->SetTextSize(0.05);
35 text1->Draw();
36
37 --- add some text (advanced)
38 --- plot the mean of the histogram at 75% of the hight of the most populated bin
39 double mean = hist->GetMean();
40 double most_populated_bin = hist->GetMaximumBin();
41 double hight_most_populated_bin = hist->GetBinContent(most_populated_bin);
42 TLatex *text2 = new TLatex(0.05,0.75*hight_most_populated_bin,Form("Mean = %5.3f",mean));
43 text2->SetTextSize(0.05);
44 text2->Draw();
45
46 return;
47
48 } // end Histogram_example_04()
49
50
51 --- Example04.C Top (30,0) (C++/I Abbrev)
Beginning of buffer
```



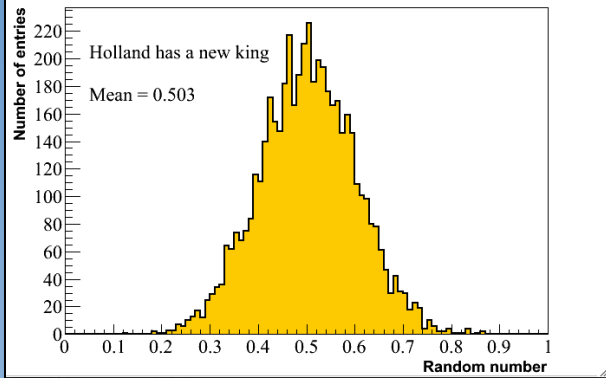
Fill histogram - random numbers

Give it your favorite color and add axes titles

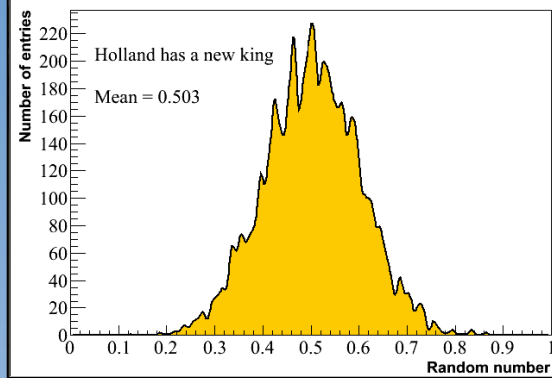
Add some text in the plot

Plot the mean at 75% of the height of the maximum bin

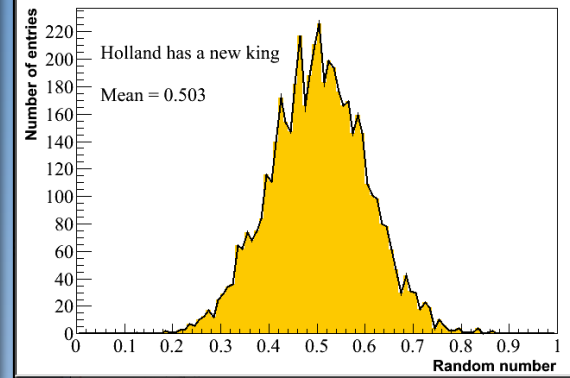
hist->Draw("hist")



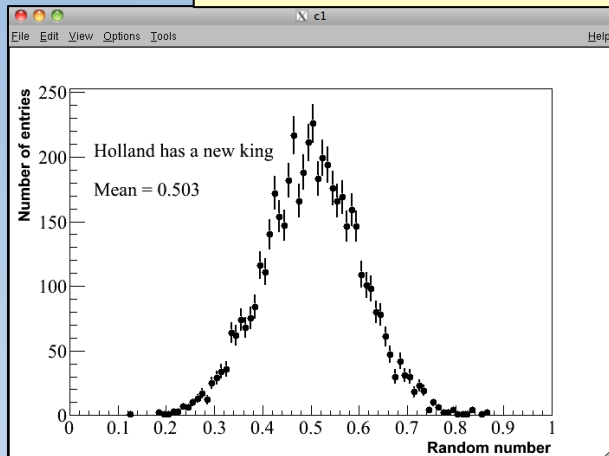
hist->Draw("l")



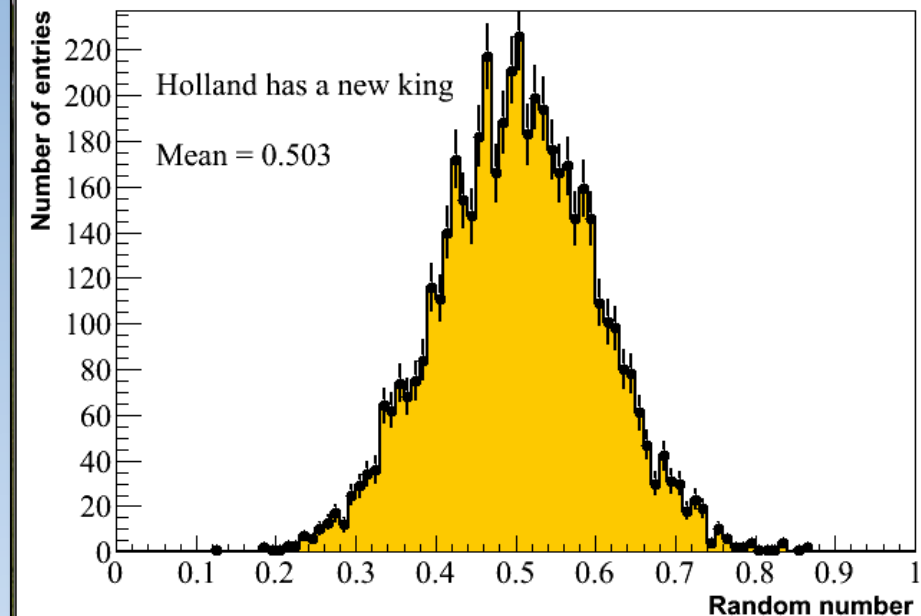
hist->Draw("c")



hist->Draw("e")



hist->Draw("hist")  
hist->Draw("e same")



Read histograms from file. Also **rebin** them

Prepare cumulative histogram

Find #events (sig, bgr, data) around 125 GeV

```

bash-3.2$ root -l

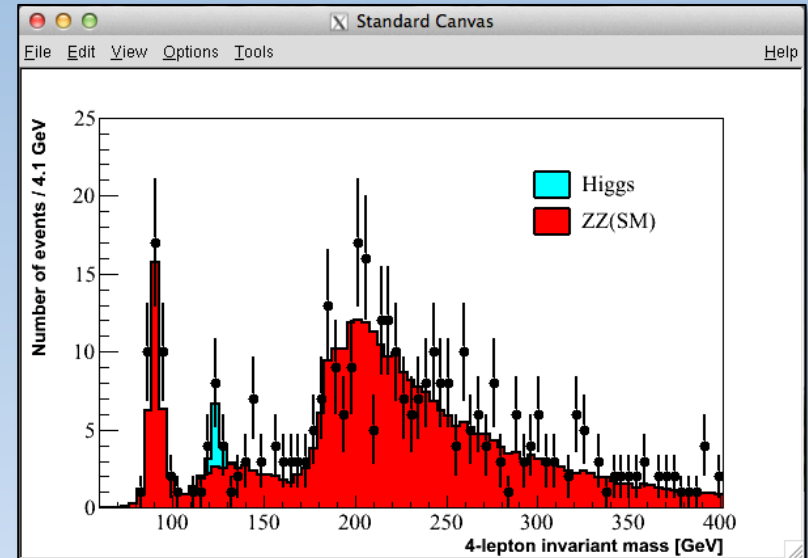
Standard RootLogon

root [0] .L Example05.C++
Info in <TUnixSystem::ACLiC>: creating shared library /Users/ivo/Dropbox/2013_07_HARSCO/
code/./Example05_C.so
root [1] Histogram_example_05[20]

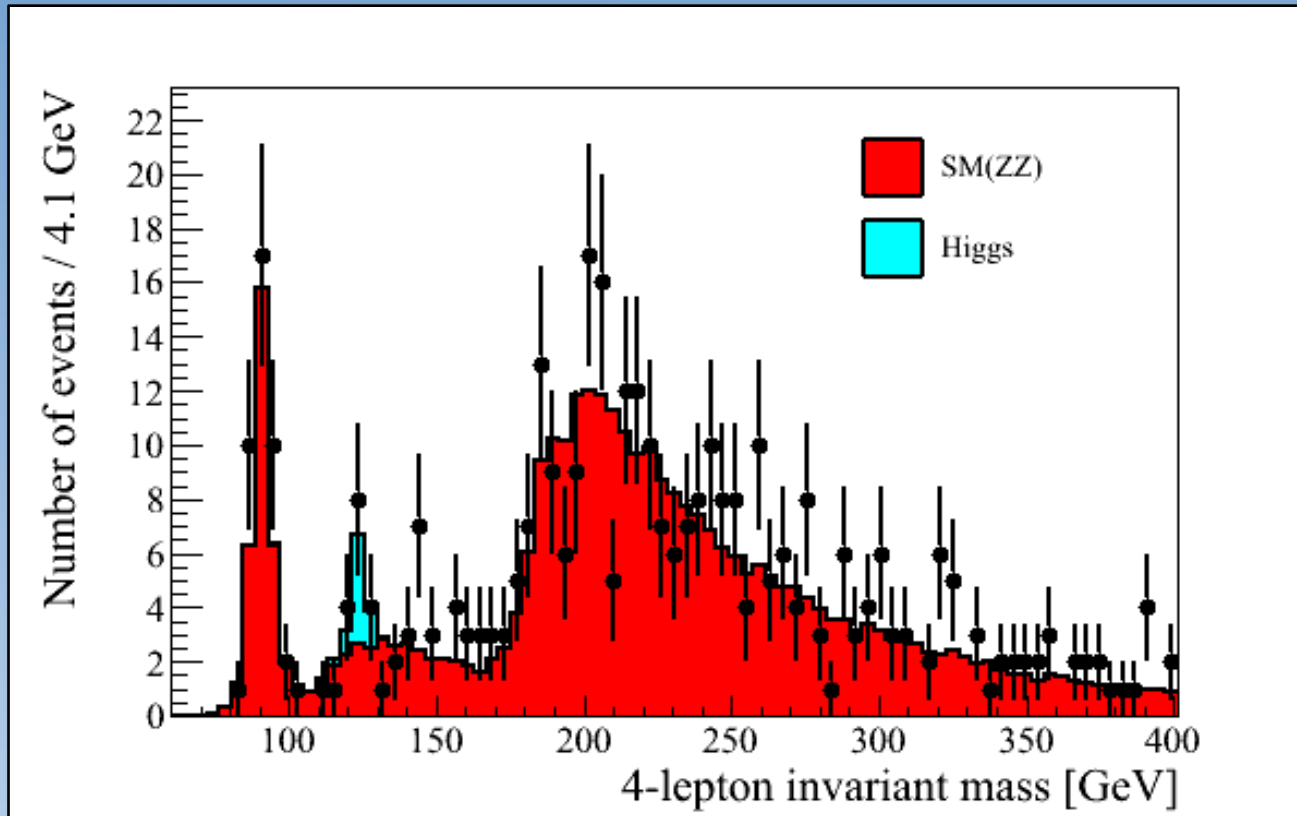
INFO: Rebinning the histograms with a factor 20. Binwidth is now 4,11 GeV

Bin 14: mass = 115,50 | Nsig = 0,23 Nbgr = 1,83 and Ndata = 1,00
Bin 15: mass = 119,61 | Nsig = 0,94 Nbgr = 2,22 and Ndata = 4,00
Bin 16: mass = 123,72 | Nsig = 4,00 Nbgr = 2,66 and Ndata = 8,00
Bin 17: mass = 127,83 | Nsig = 1,34 Nbgr = 2,54 and Ndata = 4,00
Bin 18: mass = 131,94 | Nsig = 0,07 Nbgr = 2,83 and Ndata = 1,00
Info in <TCanvas::Print>: GIF file ./Histogram_example_5.gif has been created
root [2] 

```



# Data-set for the exercises: 4 lepton mass



We'll try to squeeze as much info out of this distribution as we possibly can



# Ntuples

You'll use something like this next week during Riccardo's lectures

# Typical “event” consists of several (complex) objects

## Single variables:

Event number, run number, lumi block, time, date, #muons, #tracks, #clusters, trigger info, ...

## Tracks:

Vector-like objects: ( $d_0$ ,  $z_0$ ,  $\varphi_0$ ,  $\theta$ ,  $q/p$ ), but also isolation, particle type, cluster links, ...

## Muons, electrons, jets

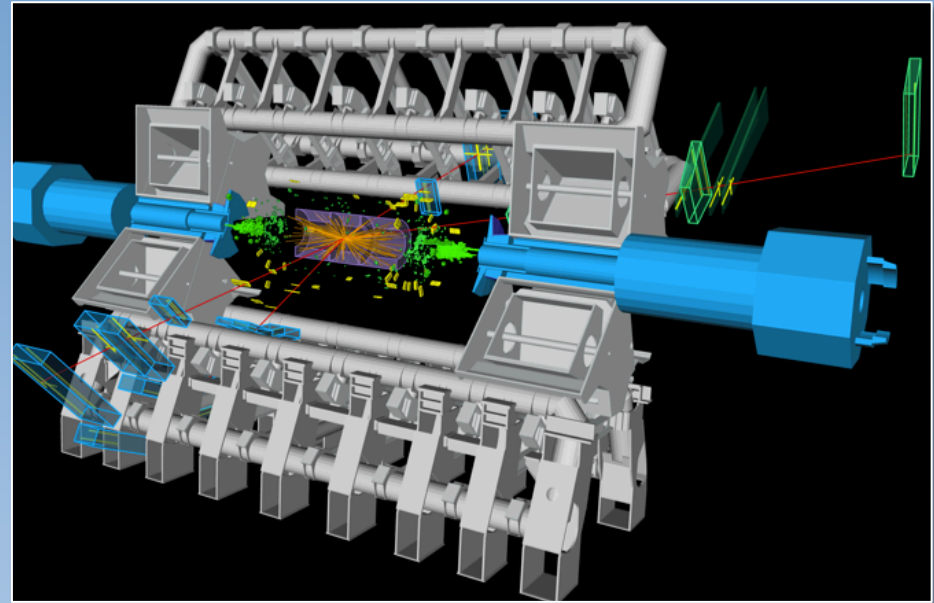
Muon algorithm types, track, energy, isolation corrections, ...

## Calorimeter clusters:

Pattern, elements, offsets, ...

## Jets:

Clusters, tracks, b-tag info, mass, ...



Complex data structures and libraries



Simplest 'flat' form is an **Ntuple**

often the endpoint of an physics analysis

# Ntuple\_create.C

"Prepare a simple Ntuple and save in file"

```
1 #include "TH1D.h"
2 #include "TFile.h"
3 #include "TNtuple.h"
4 #include "TRandom3.h"
5
6 //-----
7 void NtupleCreation(){
8 //-----
9
10 //--- Open a file
11 TFile *file = new TFile("MySimpleNtuple.root", "RECREATE");
12
13 //--- Create an Ntuple
14 TNtuple *ntuple = new TNtuple("ntuple", "my ntuple file", "x:y:z");
15
16 //--- Fill the ntuple with 1000 random variables x,y,z
17 double x, y, z;
18 TRandom3 *R = new TRandom3();
19 int Nevent = 1000;
20 for(int i_event = 0; i_event < Nevent ; i_event++){
21     x = R->Gaus(50.,5.);
22     y = R->Gaus(50.,10.);
23     z = R->Gaus(50.,15.);
24     ntuple->Fill(x,y,z);
25 }
26
27 //--- Save the file
28 file->Write();
29
30 return;
31
32 // end NtupleCreation()
33
```

Root > .L Ntuple\_create.C++  
Root > NtupleCreation()

Open the file: MySimpleNtuple.root

Create the Ntuple

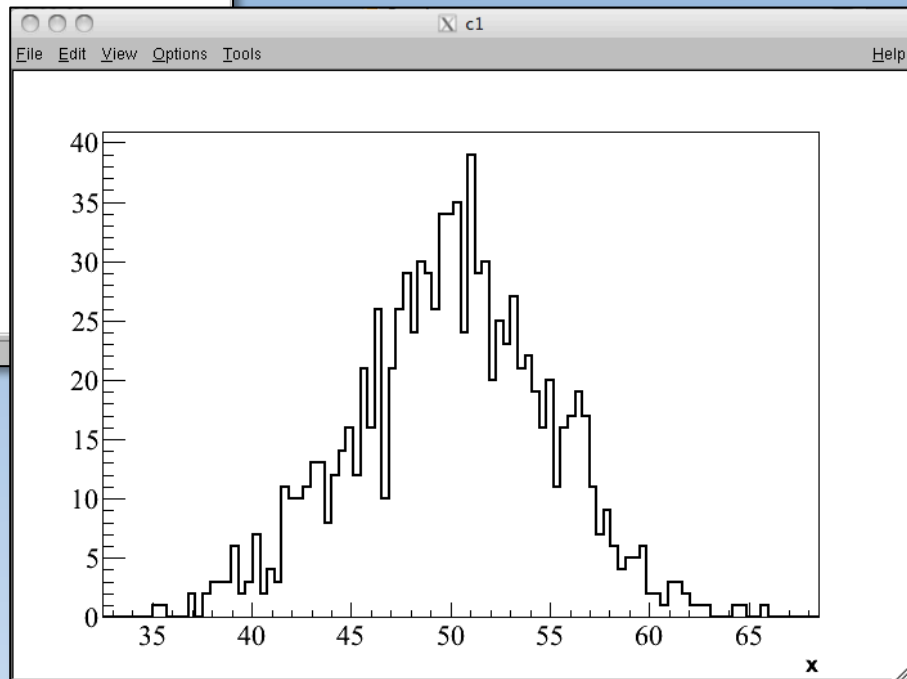
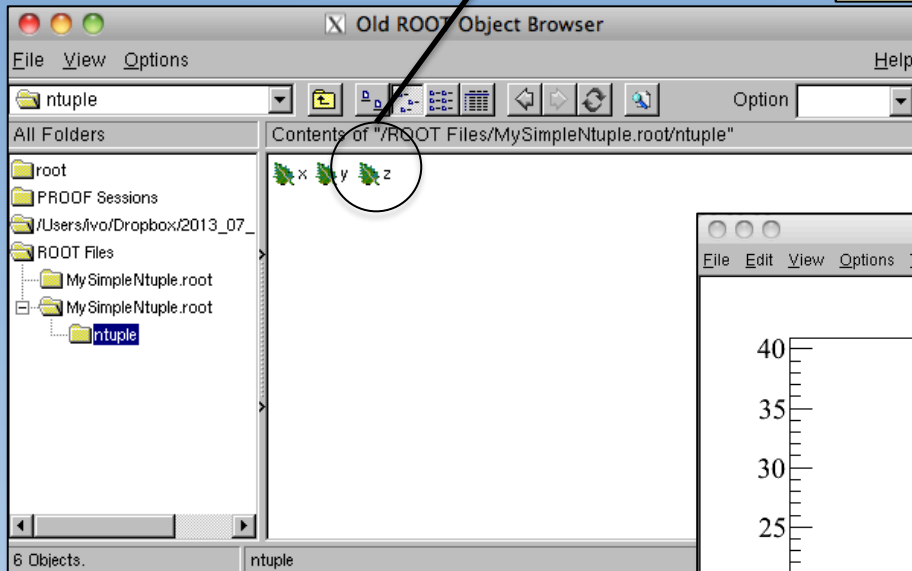
Fill the Ntuple

Write the file

# Looking at an Ntuple: browser

leaf

```
Unix > root -l MySimpleNtuple.root  
Root > TBrowser tb
```



# Looking at an Ntuple: MakeClass

```
Unix > root -l MySimpleNtuple.root
```

```
Root > .ls
```

```
Root > ntuple->MakeClass("MyNtupleAnalysis")
```

## Header file: MyNtupleAnalysis.h

```
#ifndef MyNtupleReader_h
#define MyNtupleReader_h
10
11 #include <TRoot.h>
12 #include <TChain.h>
13 #include <TFile.h>
14
15 class MyNtupleReader {
16 public:
17     TTree      *fChain; //!pointer to the analyzed TTree or TChain
18     Int_t      fCurrent; //!current Tree number in a TChain
19
20     // Declaration of leaf types
21     Float_t    x;
22     Float_t    y;
23     Float_t    z;
24
25     // List of branches
26     TBranch    *b_x;    ///
27     TBranch    *b_y;    ///
28     TBranch    *b_z;    ///
29
30     MyNtupleReader(TTree *tree=0);
31     virtual ~MyNtupleReader();
32     virtual Int_t    Cut(Long64_t entry);
33     virtual Int_t    GetEntry(Long64_t entry);
34     virtual Long64_t LoadTree(Long64_t entry);
35     virtual void     Init(TTree *tree);
36     virtual void     Loop();
37     virtual Bool_t   Notify();
38     virtual void     Show(Long64_t entry = -1);
39 };
40
```

→ Variables & types

→ GetEntry()

→ Loop()

## C-file: MyNtupleAnalysis.C

```
1 #define MyNtupleReader_cxx
2 #include "MyNtupleReader.h"
3 #include <TH2.h>
4 #include <TStyle.h>
5 #include <TCanvas.h>
6
7 void MyNtupleReader::Loop()
8 {
9     // In a ROOT session, you can do:
10     //   Root > .L MyNtupleReader.C
11     //   Root > MyNtupleReader t
12     //   Root > t.GetEntry(12); // Fill t data members with entry number 12
13     //   Root > t.Show();      // Show values of entry 12
14     //   Root > t.Show(16);    // Read and show values of entry 16
15     //   Root > t.Loop();      // Loop on all entries
16
17     if (fChain == 0) return;
18
19     Long64_t nentries = fChain->GetEntriesFast();
20
21     Long64_t nbytes = 0, nb = 0;
22     for (Long64_t jentry=0; jentry<nentries;jentry++) {
23         Long64_t ientry = LoadTree(jentry);
24         if (ientry < 0) break;
25         nb = fChain->GetEntry(jentry);   nbytes += nb;
26         // if (Cut(ientry) < 0) continue;
27     }
28 }
29
```

→ Loop()

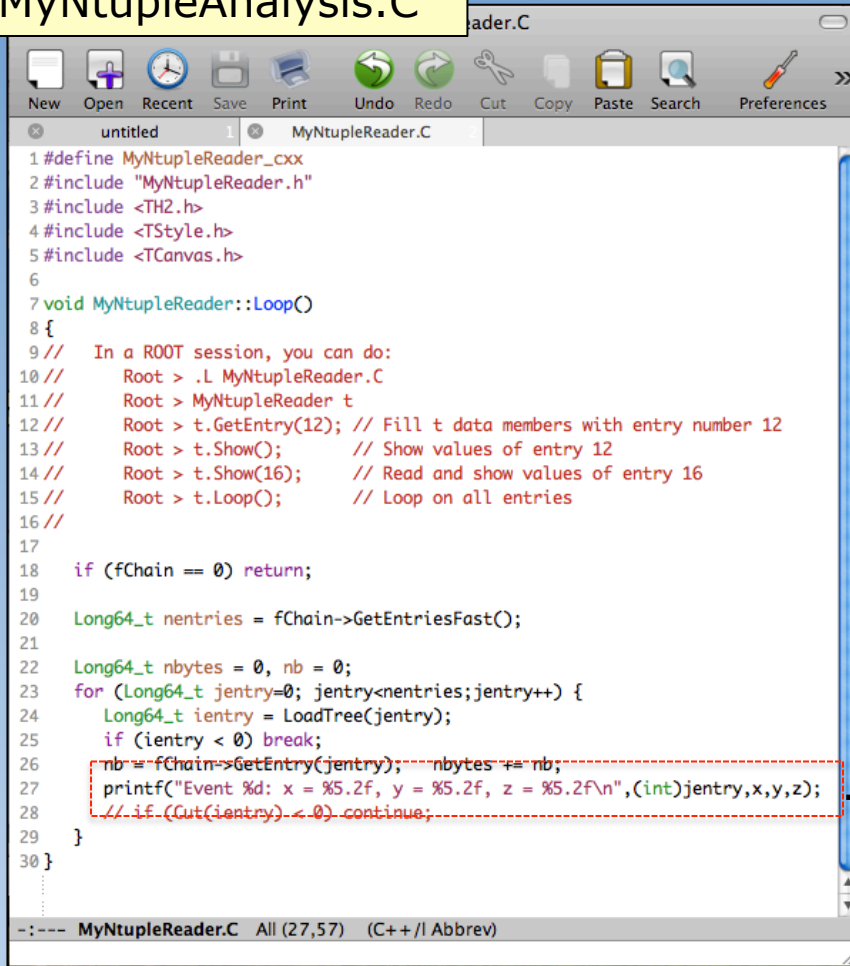
→ Loop over entries

→ Somewhere a link to MySimpleNtuple.root



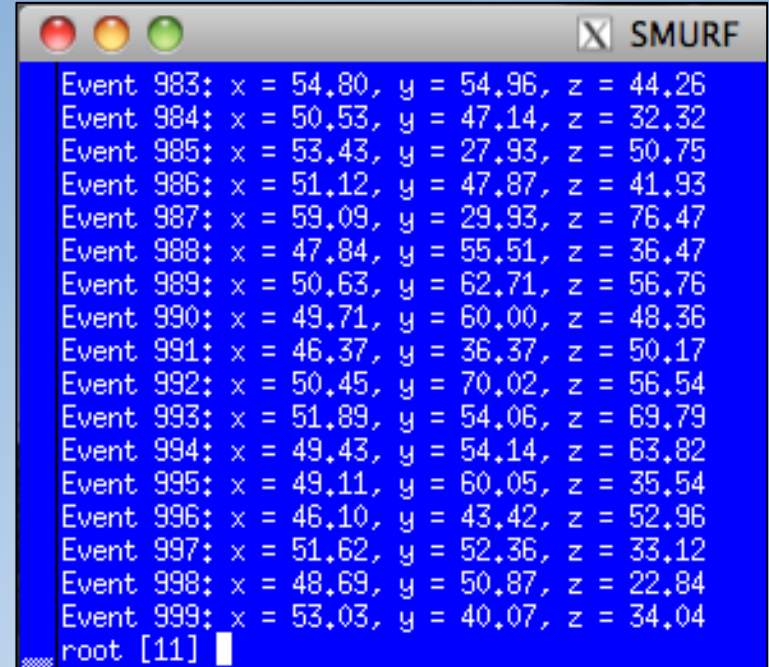
# Running your code

## MyNtupleAnalysis.C



```
1 #define MyNtupleReader_cxx
2 #include "MyNtupleReader.h"
3 #include <TH2.h>
4 #include <TStyle.h>
5 #include <TCanvas.h>
6
7 void MyNtupleReader::Loop()
8 {
9 // In a ROOT session, you can do:
10 // Root > .L MyNtupleReader.C
11 // Root > MyNtupleReader t
12 // Root > t.GetEntry(12); // Fill t data members with entry number 12
13 // Root > t.Show(); // Show values of entry 12
14 // Root > t.Show(16); // Read and show values of entry 16
15 // Root > t.Loop(); // Loop on all entries
16 //
17
18 if (fChain == 0) return;
19
20 Long64_t nentries = fChain->GetEntriesFast();
21
22 Long64_t nbytes = 0, nb = 0;
23 for (Long64_t jentry=0; jentry<nentries;jentry++) {
24     Long64_t ientry = LoadTree(jentry);
25     if (ientry < 0) break;
26     nb = fChain->GetEntry(jentry); nbytes += nb;
27     printf("Event %d: x = %5.2f, y = %5.2f, z = %5.2f\n", (int)jentry, x, y, z);
28     // if (Cut(ientry) < 0) continue;
29 }
30 }
```

```
Unix > root
Root > .L MyNtupleReader.C++
Root > MyNtupleReader mnrr
Root > mnrr.Loop()
```



```
SMURF
Event 983: x = 54.80, y = 54.96, z = 44.26
Event 984: x = 50.53, y = 47.14, z = 32.32
Event 985: x = 53.43, y = 27.93, z = 50.75
Event 986: x = 51.12, y = 47.87, z = 41.93
Event 987: x = 59.09, y = 29.93, z = 76.47
Event 988: x = 47.84, y = 55.51, z = 36.47
Event 989: x = 50.63, y = 62.71, z = 56.76
Event 990: x = 49.71, y = 60.00, z = 48.36
Event 991: x = 46.37, y = 36.37, z = 50.17
Event 992: x = 50.45, y = 70.02, z = 56.54
Event 993: x = 51.89, y = 54.06, z = 69.79
Event 994: x = 49.43, y = 54.14, z = 63.82
Event 995: x = 49.11, y = 60.05, z = 35.54
Event 996: x = 46.10, y = 43.42, z = 52.96
Event 997: x = 51.62, y = 52.36, z = 33.12
Event 998: x = 48.69, y = 50.87, z = 22.84
Event 999: x = 53.03, y = 40.07, z = 34.04
root [11]
```

ONE extra line to MyNtupleAnalysis.C:

```
printf("Event %d: x = %5.2f, y = %5.2f, z = %5.2f\n", (int)jentry, x, y, z);
```

# Statistics

# Statistics

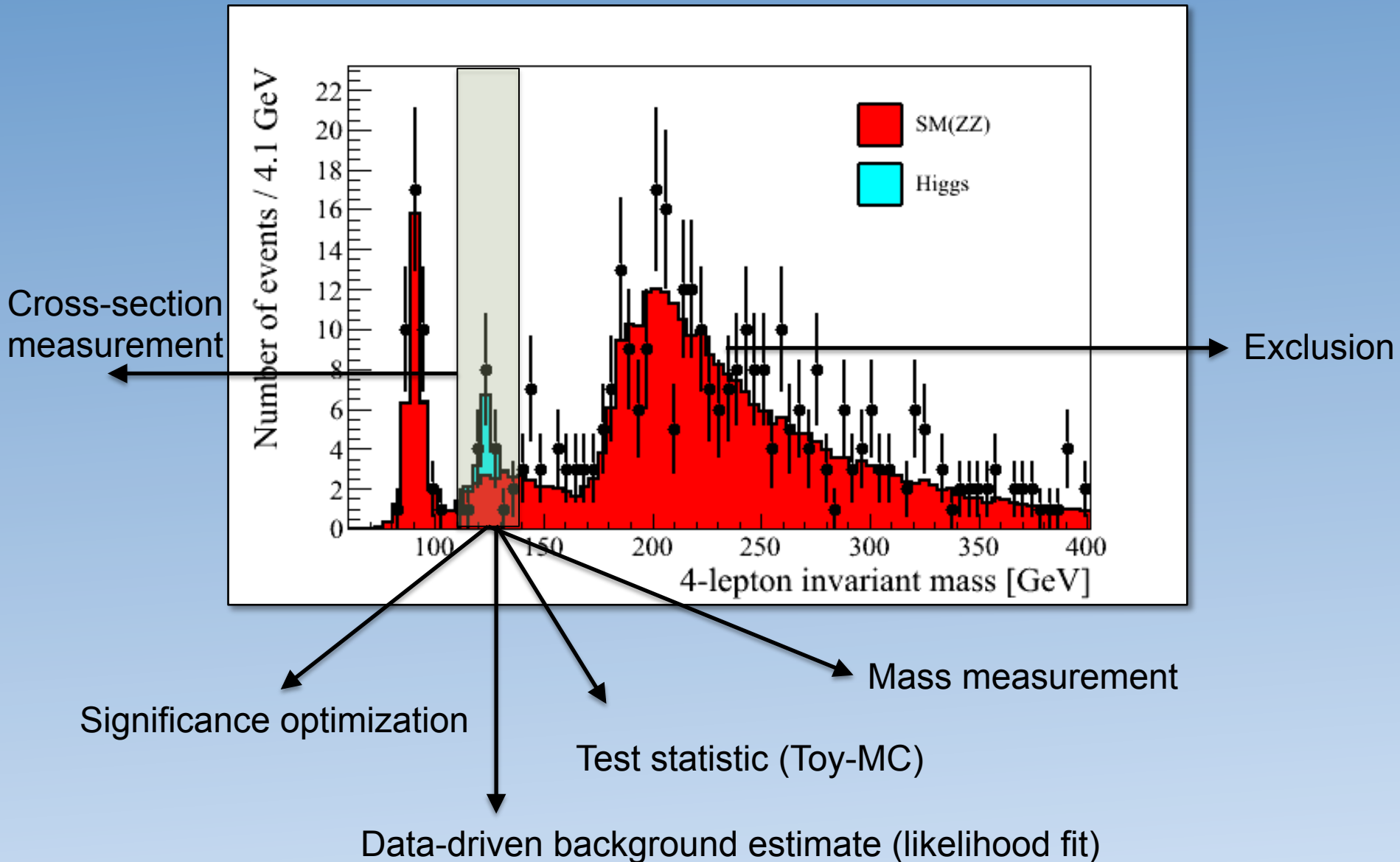
## **1) Hypotheses testing & search:**

*Significance (definition and optimization)*

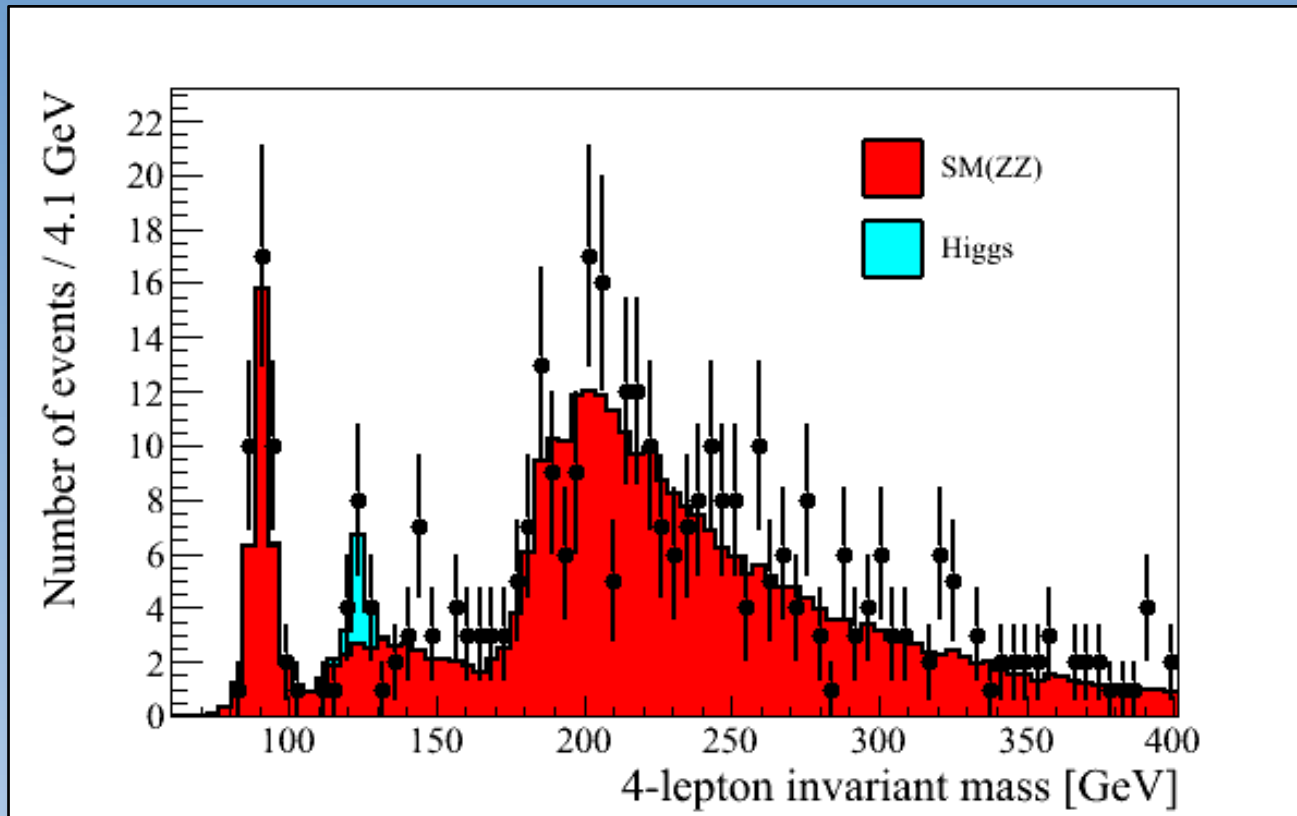
## **2) Measurement:**

*Side-band (likelihood) fit to estimate background*

# Data-set for the exercises: 4 lepton mass



# Data-set for the exercises: 4 lepton mass



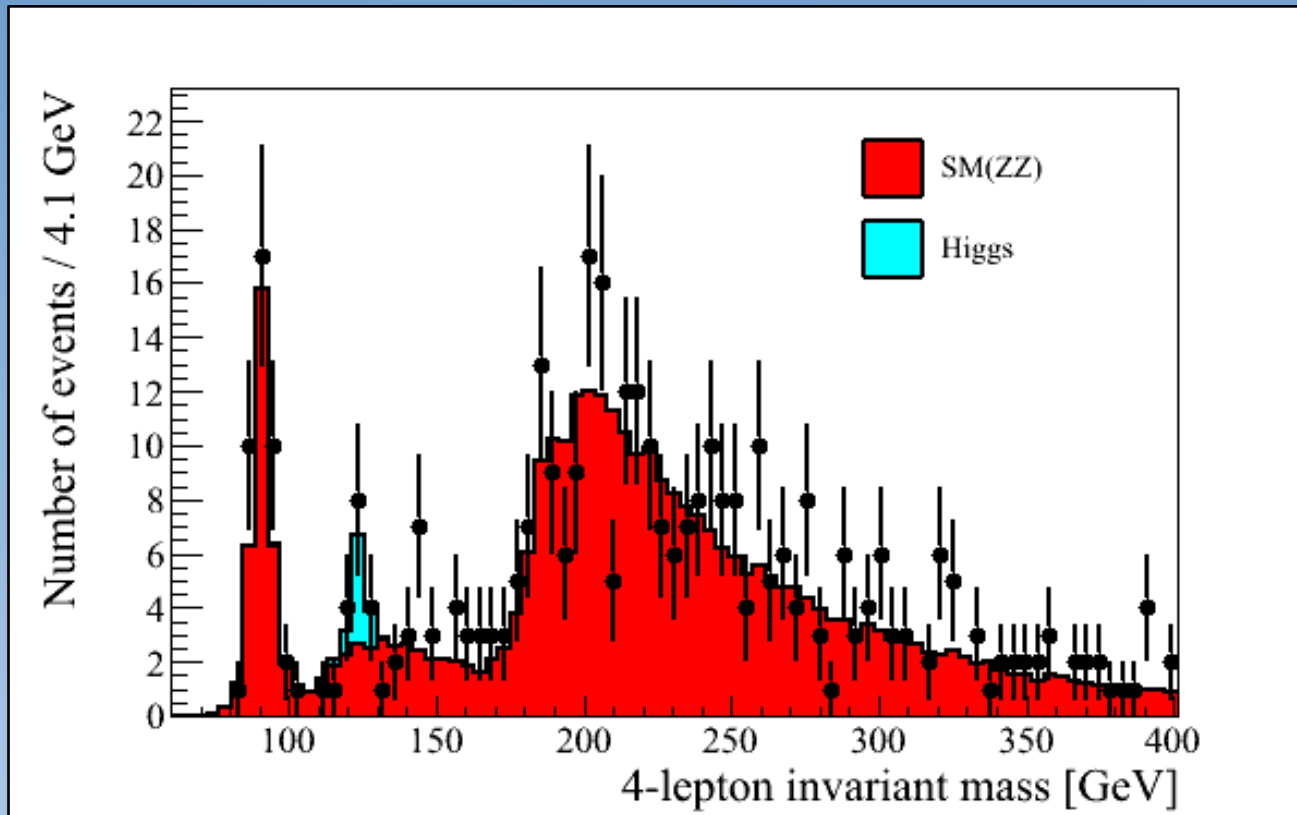
Full set of exercises:

[https://www.nikhef.nl/~ivov/Talks/2013\\_03\\_21\\_DESY\\_HiggsExercises.pdf](https://www.nikhef.nl/~ivov/Talks/2013_03_21_DESY_HiggsExercises.pdf)

Today we will only do a few of them



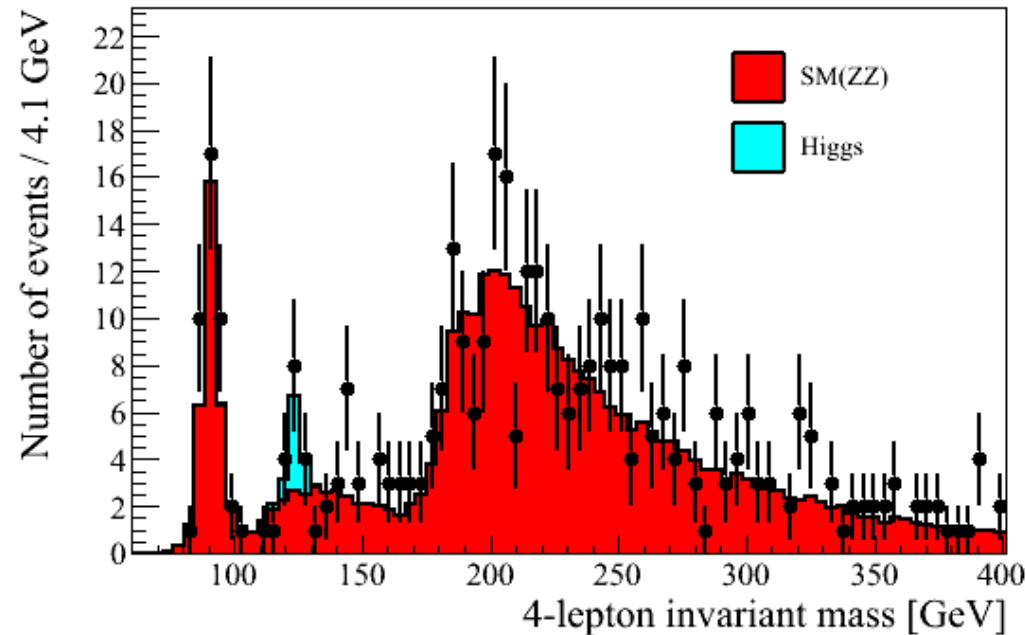
# Data-set for the exercises: 4 lepton mass



Note: - Original histograms have 200 MeV bins  
- This is fake data

In the 1<sup>st</sup> exercise we use re-binned histograms (4 GeV bins)

## our fake 4-lepton mass distribution



### Set 1: Measurements

1. Data-driven background estimate (sideband likelihood fit + Poisson)

#### Optional:

2. Higgs signal cross-section measurement
3. *Optional: simultaneous mass + signal cross-section measurement*

### Set 2: hypothesis testing

1. Significance optimization (counting)

#### Optional:

2. Compute test statistic (beyond counting)
3. Toy-MC and test statistic distribution
4. Interpretation: discovery
5. Interpretation: exclusion

# Statistics

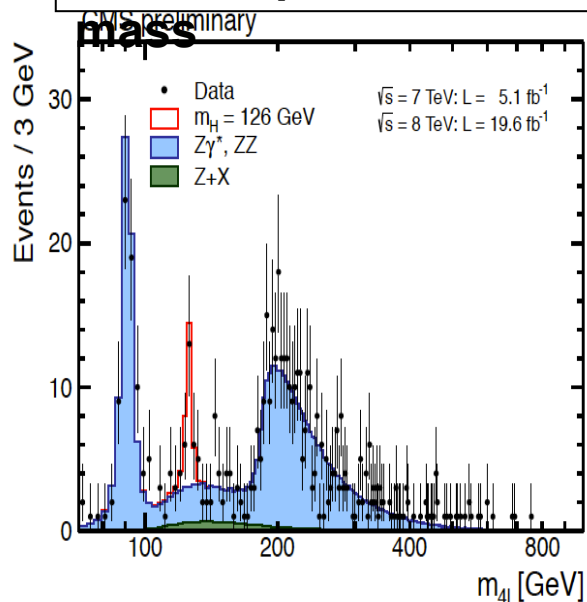
## **1) Hypotheses testing & search:**

*Significance (definition and optimization)*

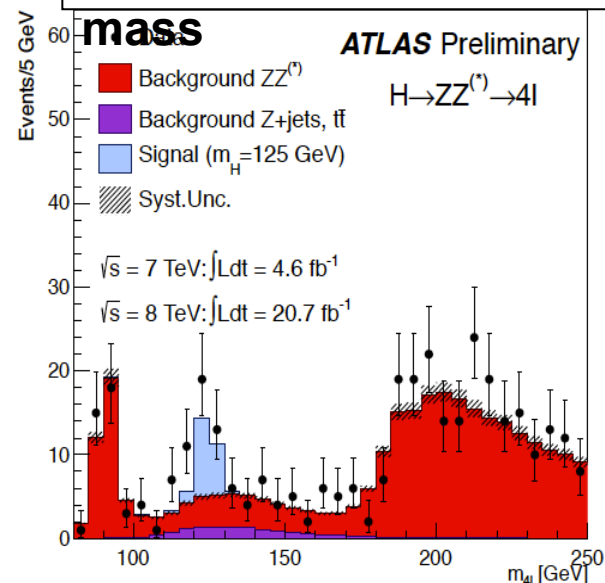
## **2) Measurement:**

*Side-band (likelihood) fit to estimate background*

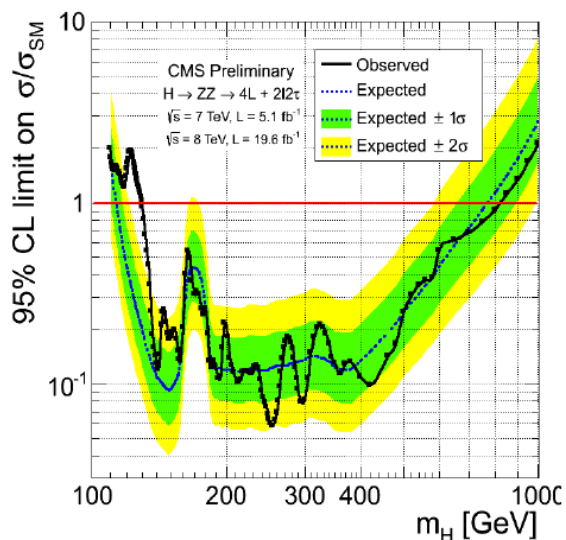
## CMS 4 lepton invariant



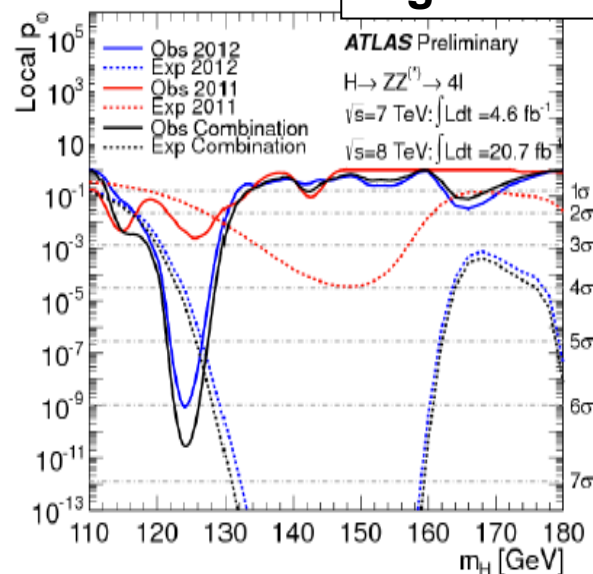
## ATLAS 4 lepton invariant



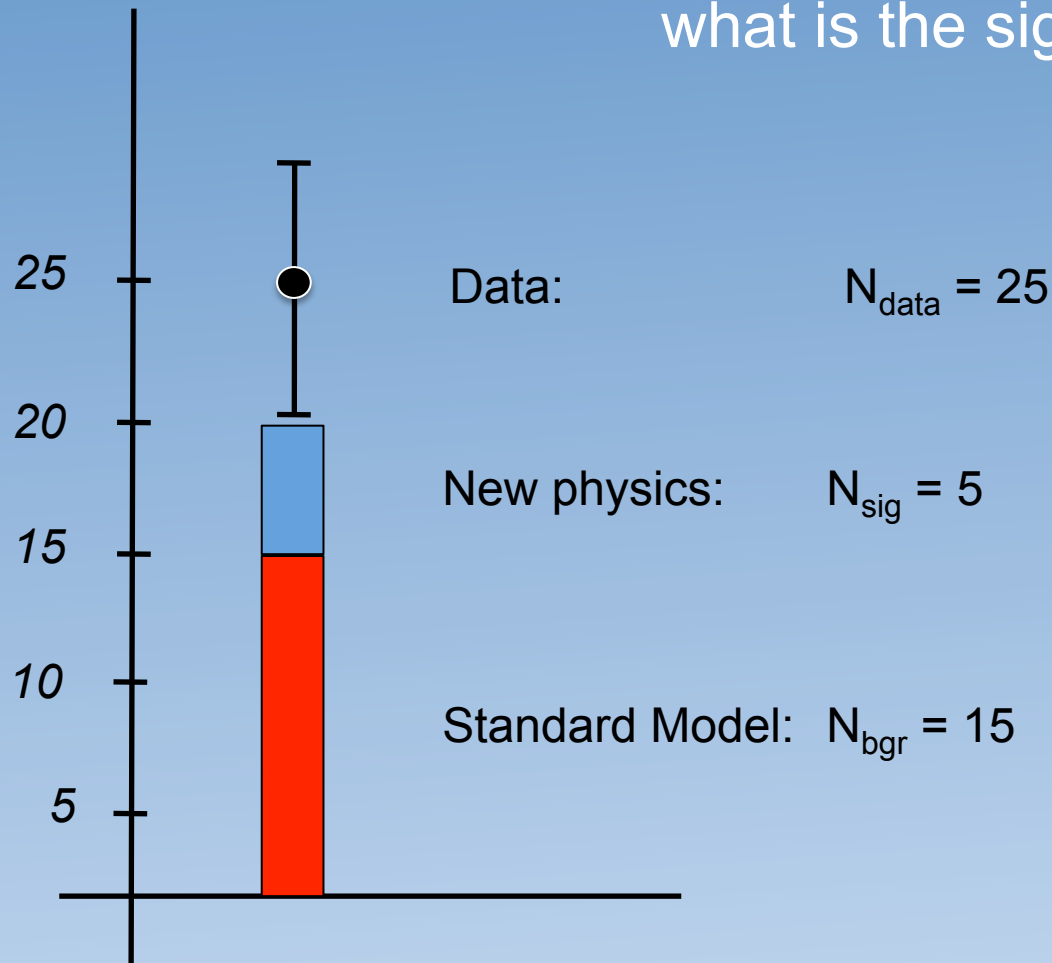
## Excluded cross-sections



## Significances



General remark :  
what is the significance ?



*Significance: probability to observe  $N$  events (or even more) under the background-only hypothesis*



## Observed significance:

$$\int_{25}^{\infty} \text{Poisson}(N | 15) dN = 0.0112 \quad \leftarrow p\text{-value}$$
$$= 2.28 \text{ sigma} \quad \leftarrow \text{significance}$$

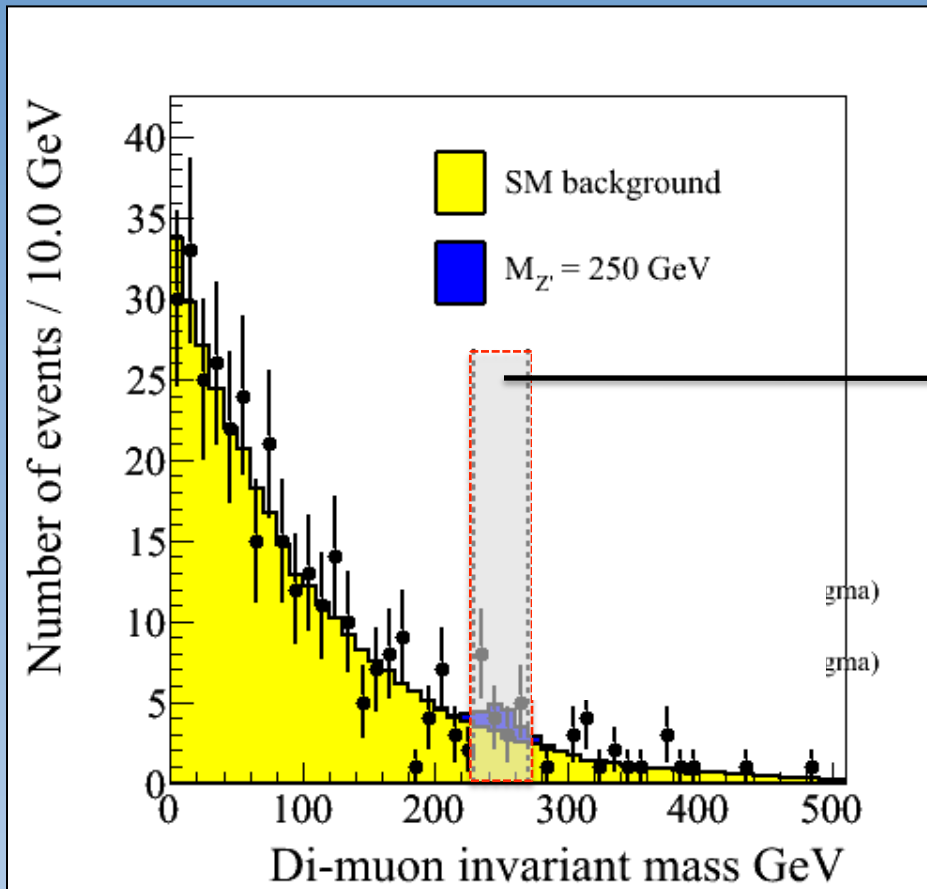
## Expected significance:

$$\int_{20}^{\infty} \text{Poisson}(N | 15) dN = 0.1248$$
$$= 1.15 \text{ sigma}$$

Discovery if  $p\text{-value} < 2.87 \times 10^{-7}$

→ 39 events

# Counting events in a mass window



Standard Model

SM	10
Higgs	5
Data	12

Ok, now what ?

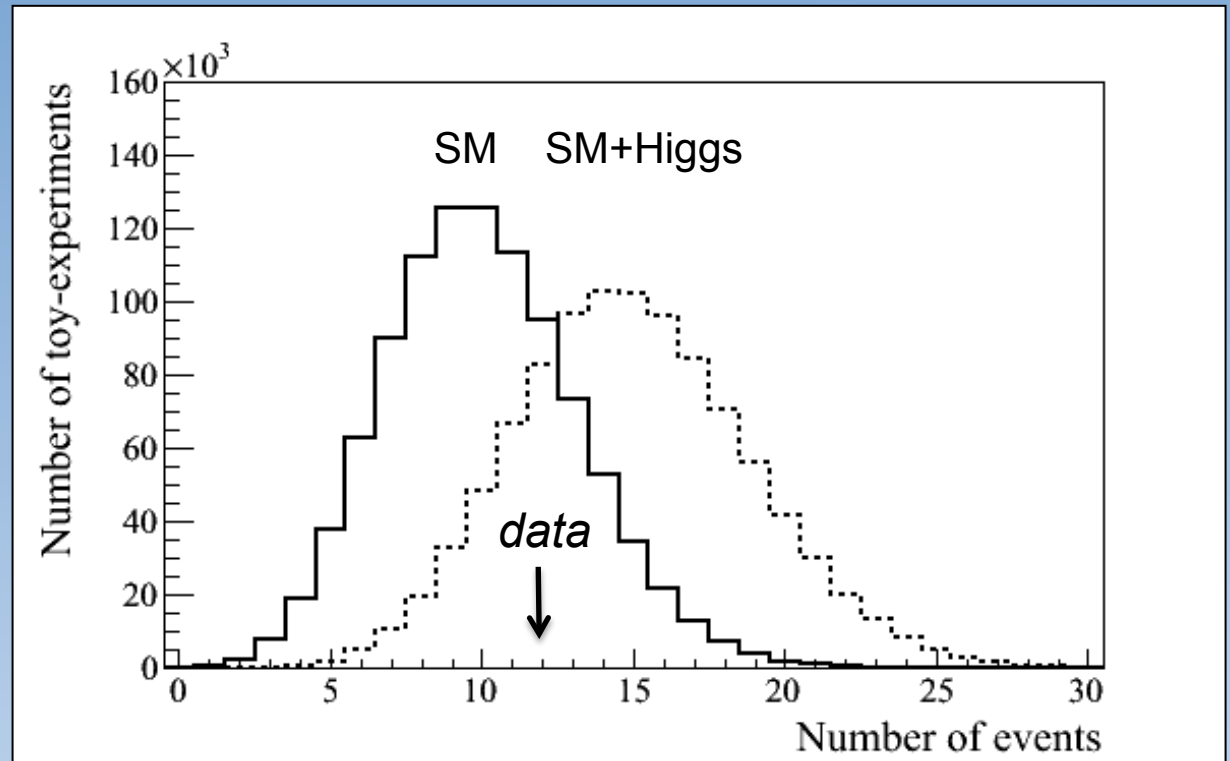
*Significance: probability to observe  $N$  events (or even more) under the background-only hypothesis*

## Standard Model

SM	10
Higgs	5
Data	12

Ok, now what ?

## *Poisson distribution*



# Interpretation

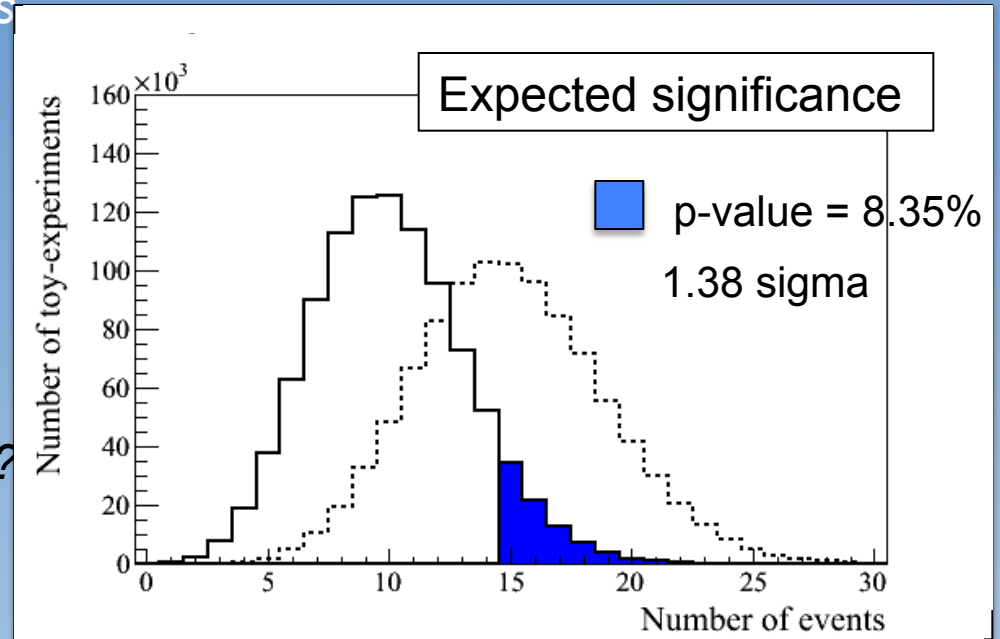
optimistic: discovery

# Discovery-aimed: p-value and significance

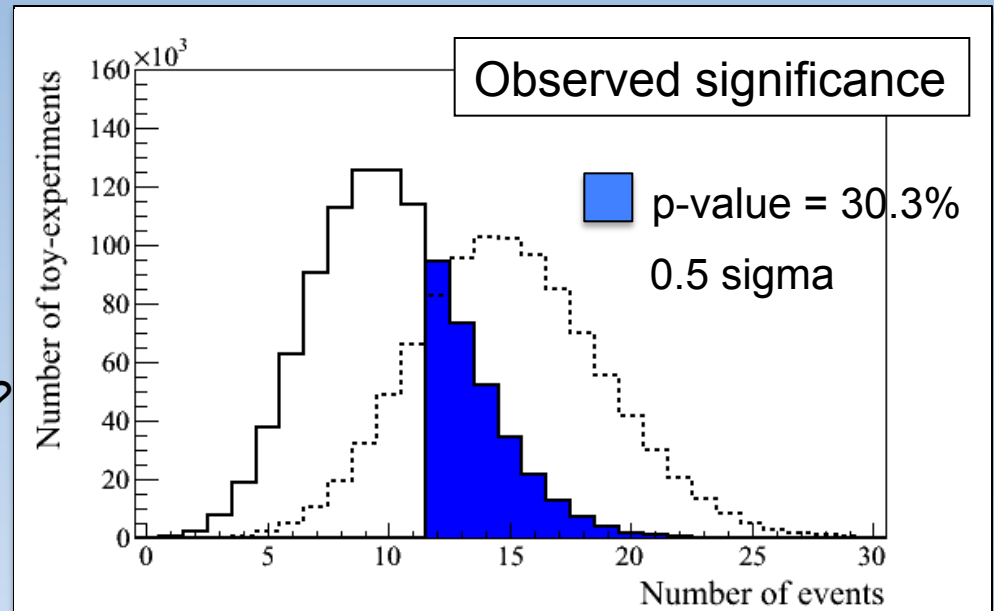
*incompatibility with SM-only hypothesis*

SM	10
Higgs	5
Data	12

1) What is the **expected** significance ?



2) What is the **observed** significance ?



# Discovery-aimed: p-value and significance

SM	10
Higgs	5

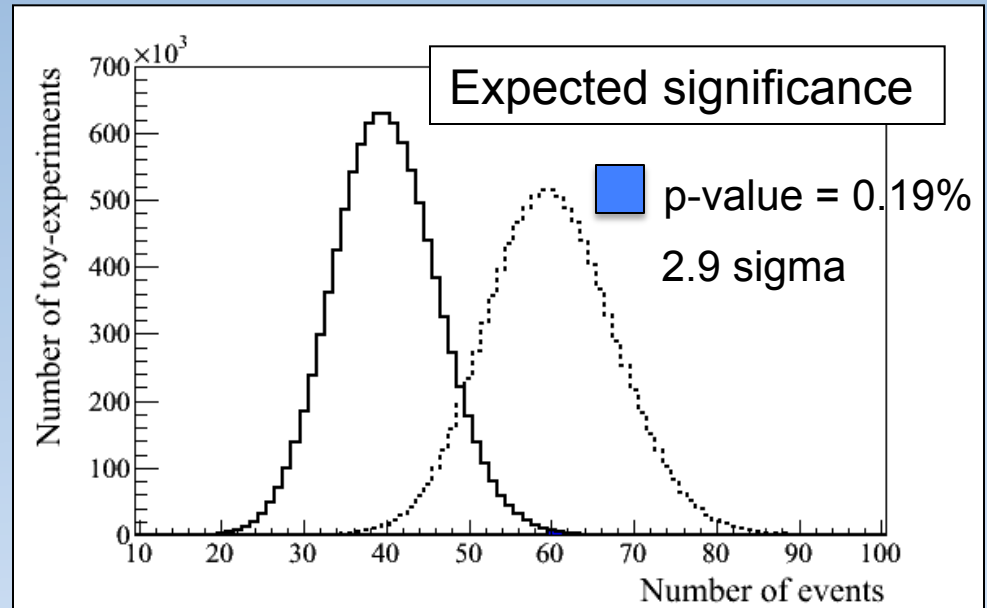
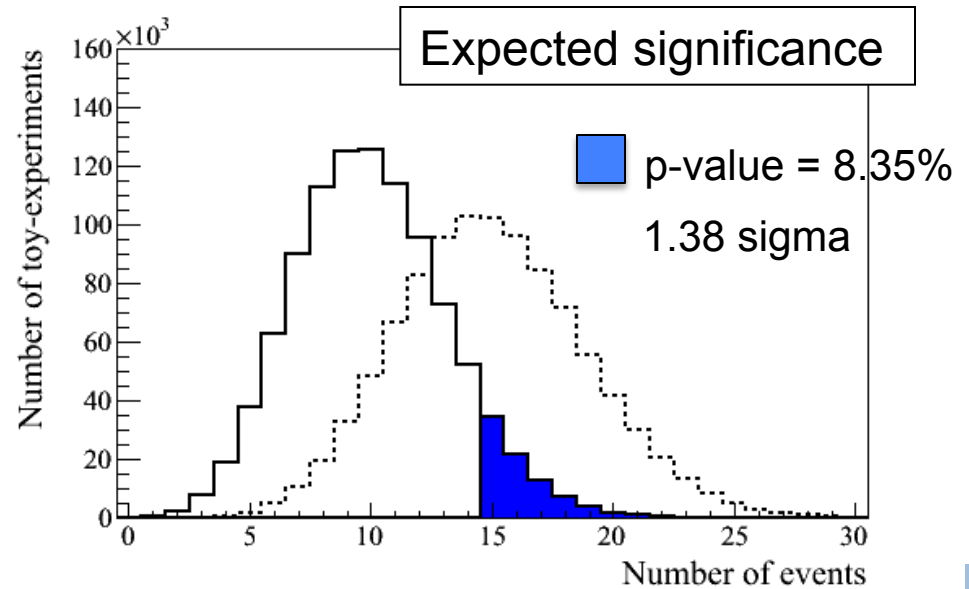
3) *At what Lumi do you expect to be able to claim a discovery ?*

**3 times more  
LUMINOSITY**



SM	30
Higgs	15

Discovery if  $p\text{-value} < 2.87 \times 10^{-7}$

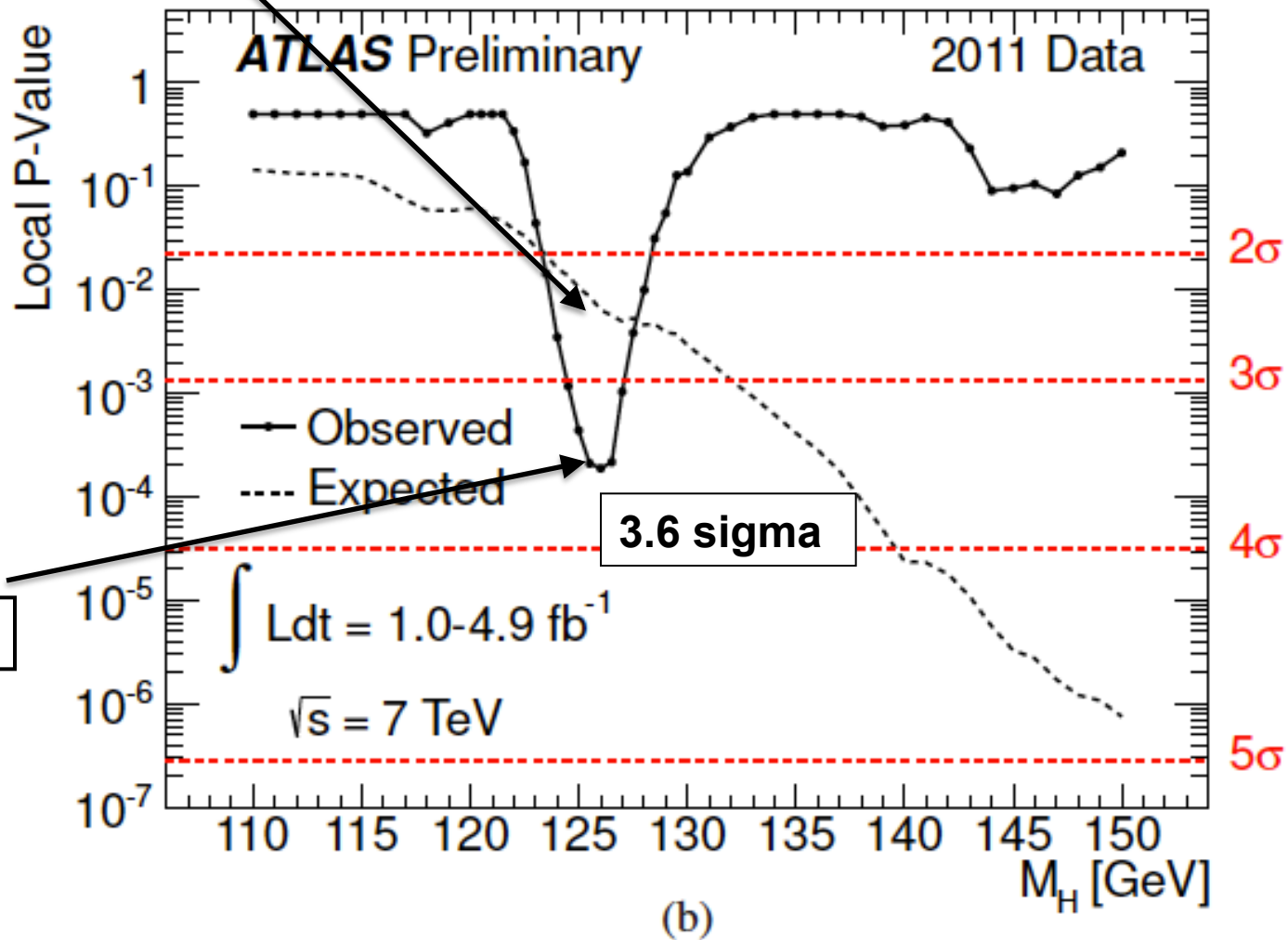




# Understanding the official ATLAS plot

exected p-value

observed p-value



# Interpretation

pessimistic: exclusion

# When / how do you exclude a signal

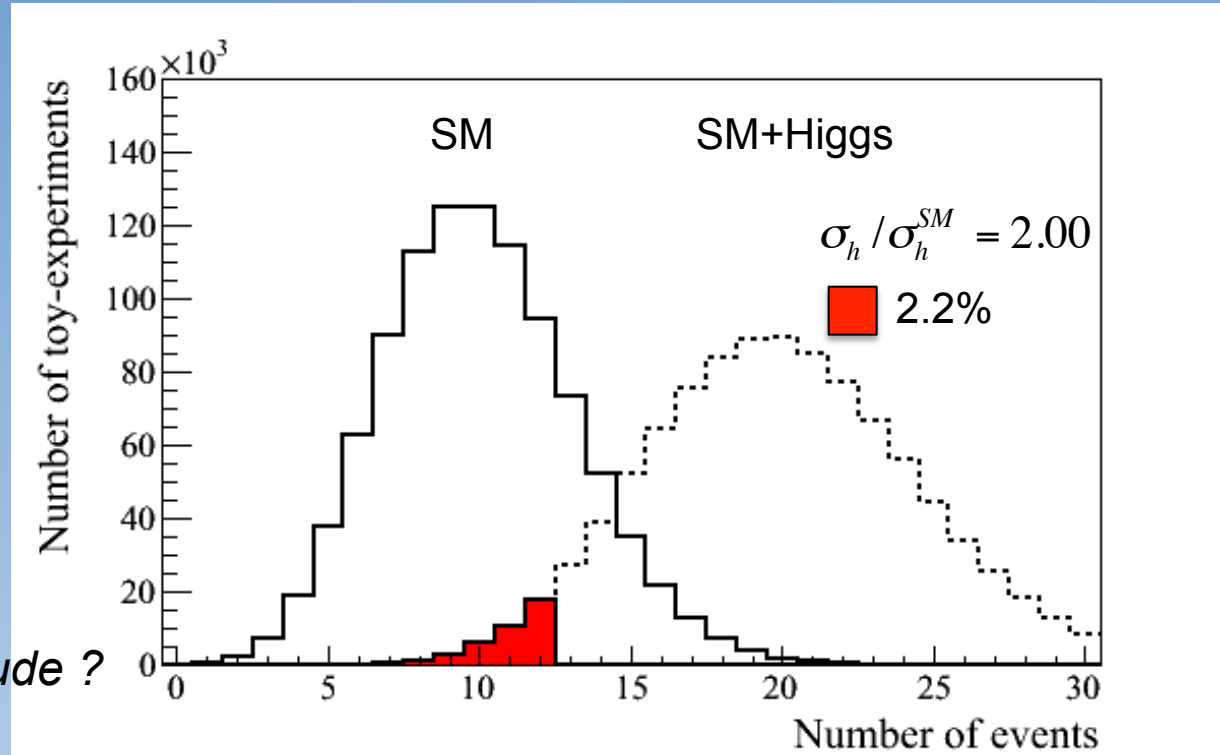
*Incompatibility with s+b hypothesis*

Standard Model

SM	10
Higgs	5
Data	12

*Can we exclude the SM+Higgs hypothesis ?*

*What  $\sigma_h/\sigma_h^{SM}$  can we exclude ?*



*Exclusion: probability to observe  $N$  events (or even less) under the signal + background hypothesis*

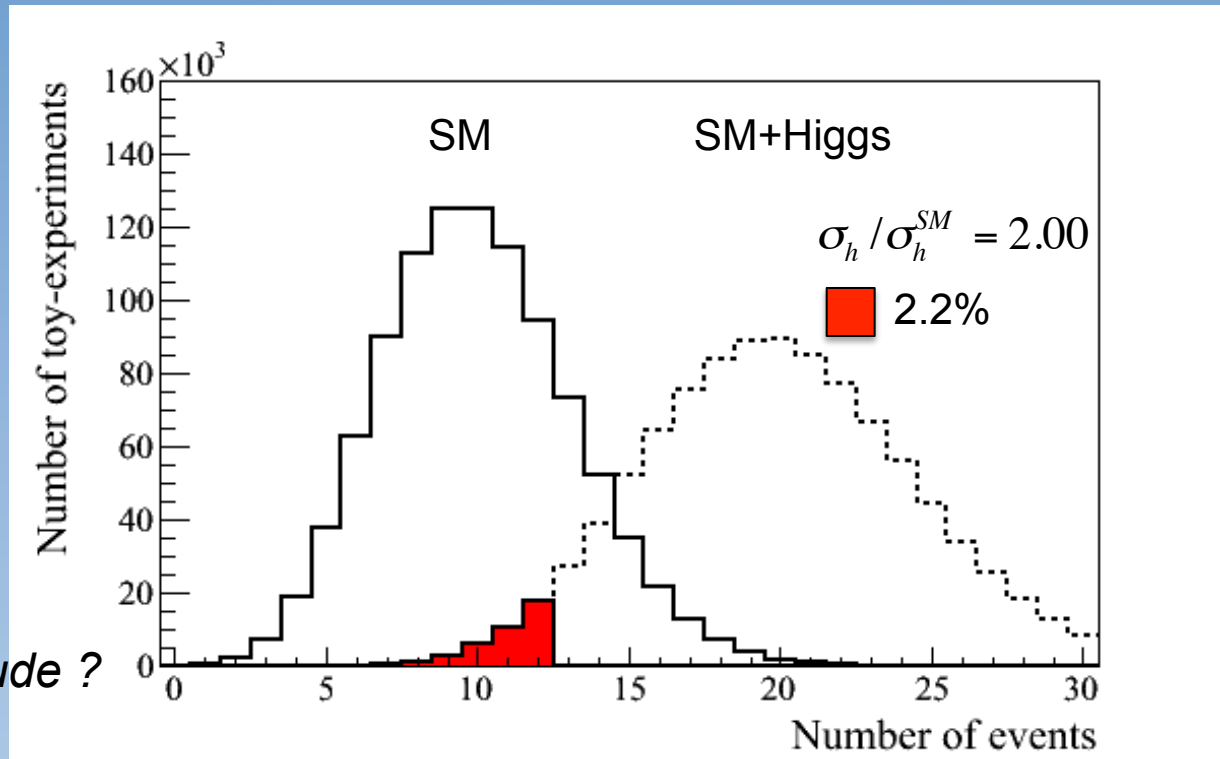
# When / how do you exclude a signal

Standard Model

SM	10
Higgs	5
Data	12

Can we exclude the SM+Higgs hypothesis ?

What  $\sigma_h/\sigma_h^{SM}$  can we exclude ?



$\sigma/\sigma_{SM}$	SM	# data	SM+Higgs	
1.0	10	12	15.0	18.5 %
1.5	10	12	17.5	6.8%
2.0	10	12	20.0	2.2%

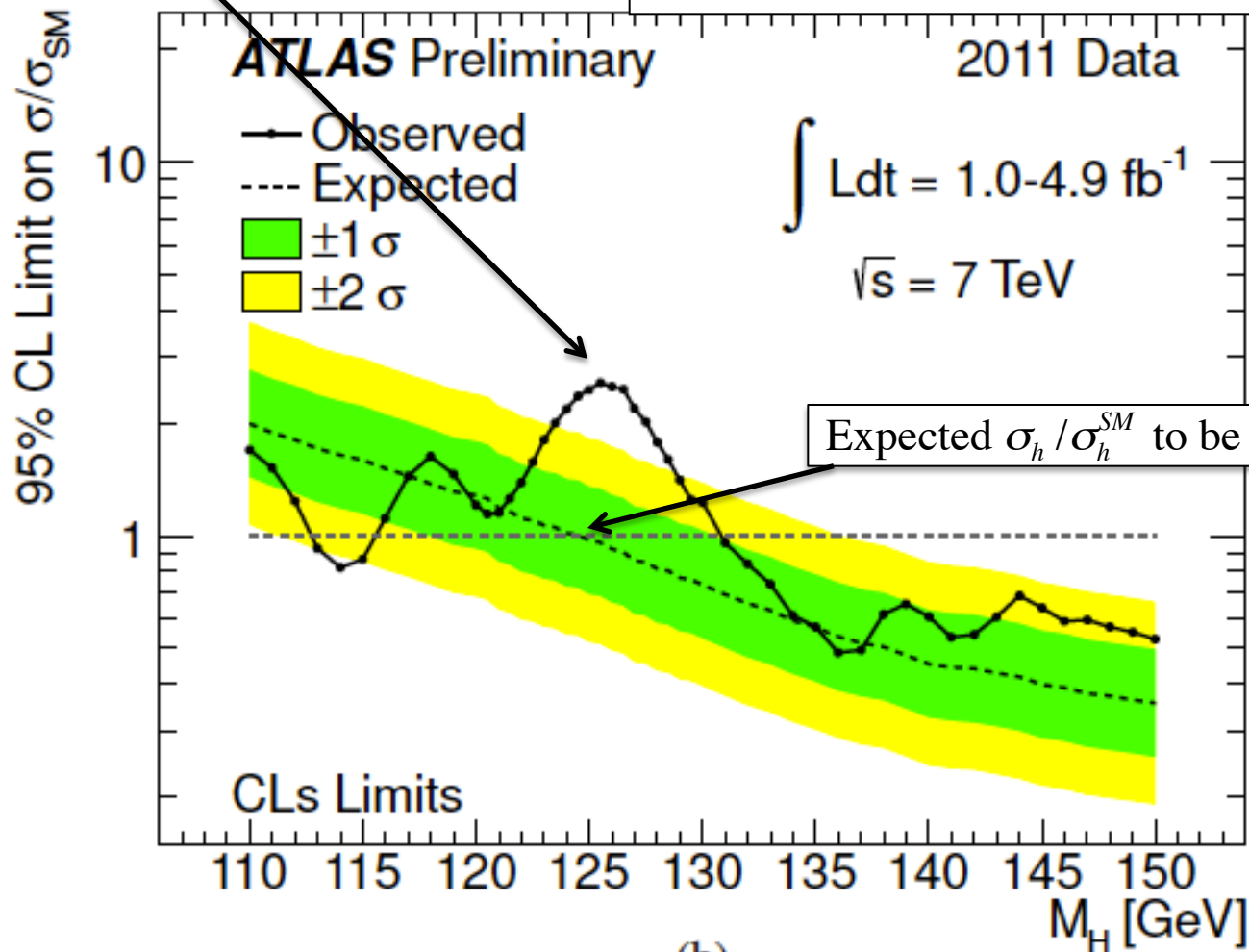
excluded

Expected exclusion ? Use mean SM instead of Ndata

**Observed** excluded cross-section,  $\sigma_h/\sigma_h^{SM}$  , = 1.64

Observed  $\sigma_h / \sigma_h^{SM}$  to be excluded

## Excluded cross-sections



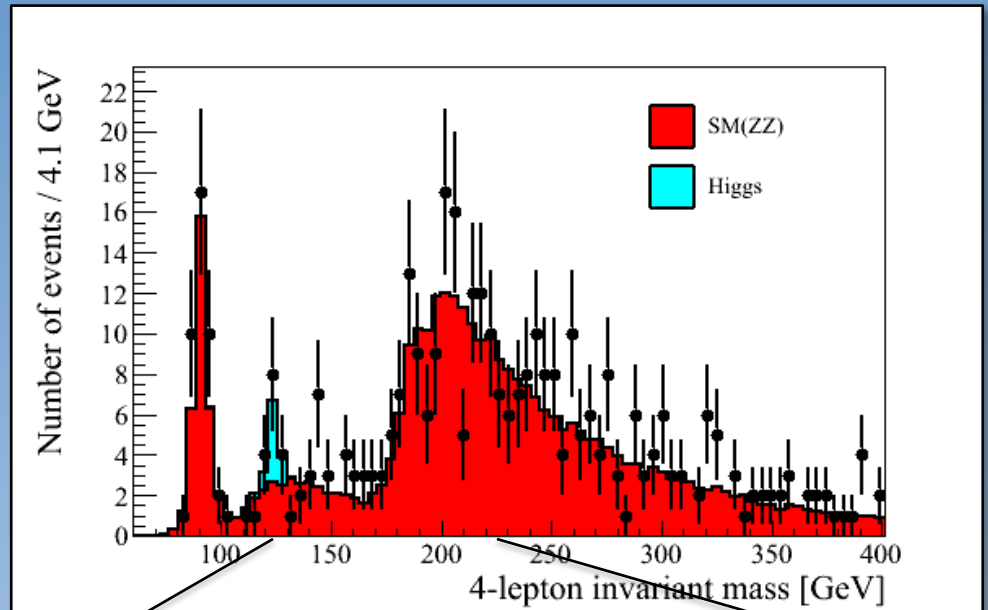
We will be optimistic today ... discovery

## Create the 4-lepton mass plot

```
root> .L Hasco_skeleton.C++  
root> MassPlot(20)
```

↓  
Rebin-factor

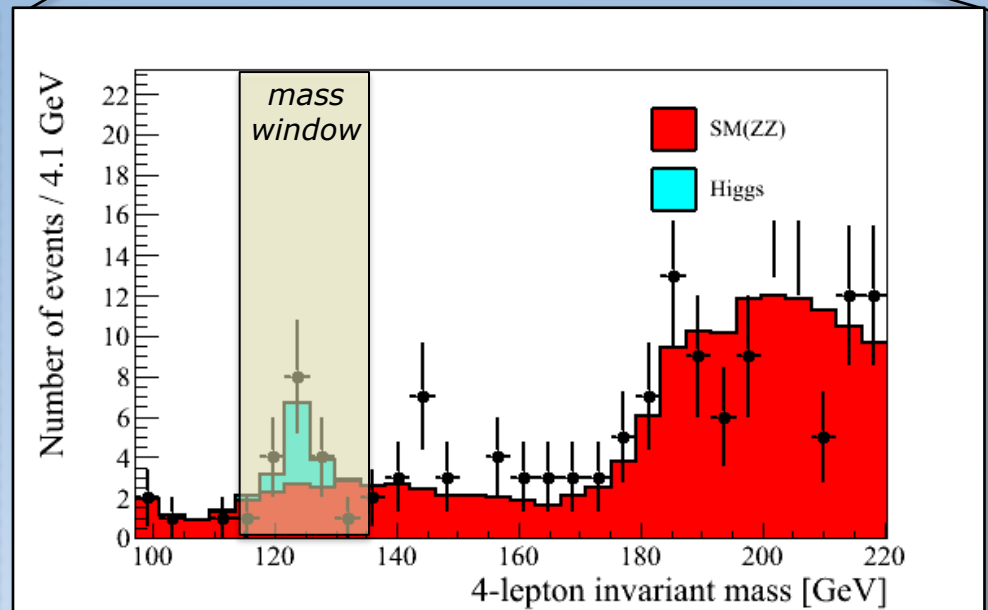
*hist: h\_bgr, h\_sig, h\_data*



## Summary in signal mass region (using 200 MeV bins and 10 GeV window)

Ndata = 16  
Nbgr = 6.42  
Nsig = 5.96

Exercises: significance





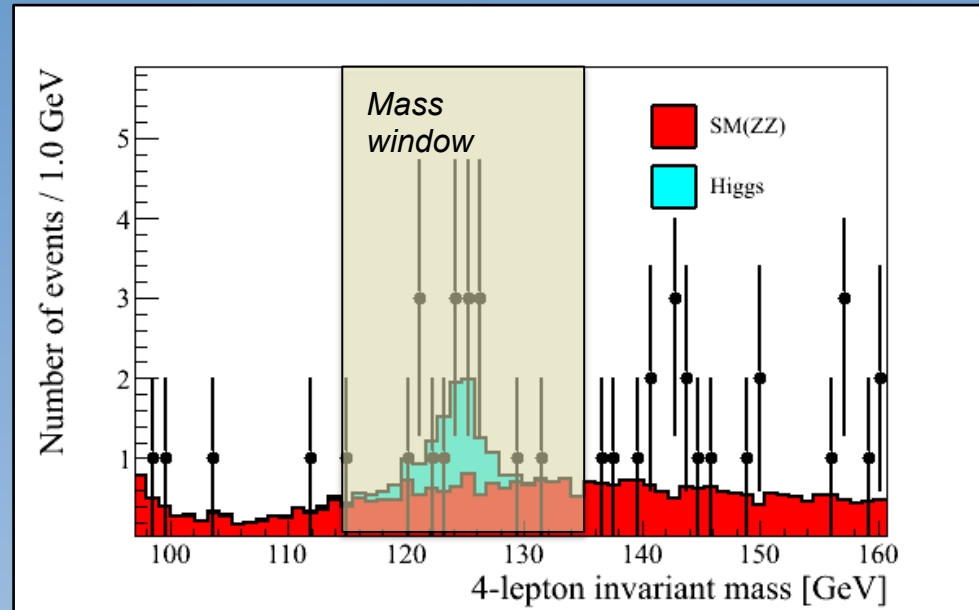
# Exercise 3

## Optimizing the counting experiment

### Code you could use:

```
IntegratePoissonFromRight()
```

```
Significance_Optimization()
```



### Exercise 1: significance optimization of search window (Poisson counting)

- 3.1** Find the window that optimizes the expected significance
- 3.2** Find the window that optimizes the observed significance (never ever do this again)
- 3.3** Find the window that optimizes the expected significance for 5x higher luminosity
- 3.4** At what luminosity do you expect to be able to make a discovery ?

## More complex test statistics: beyond simple counting

Likelihood ratio:

$$X = -2\ln(Q), \text{ with } Q = \frac{L(\mu_s = 1)}{L(\mu_s = 0)} = \frac{\text{red ball}}{\text{blue ball}}$$

Tevatron-style:

$$X = -2\ln(Q), \text{ with } Q = \frac{L(\mu_s = 1, \hat{\theta}_{(\mu_s=1)})}{L(\mu_s = 0, \hat{\theta}_{(\mu_s=0)})}$$

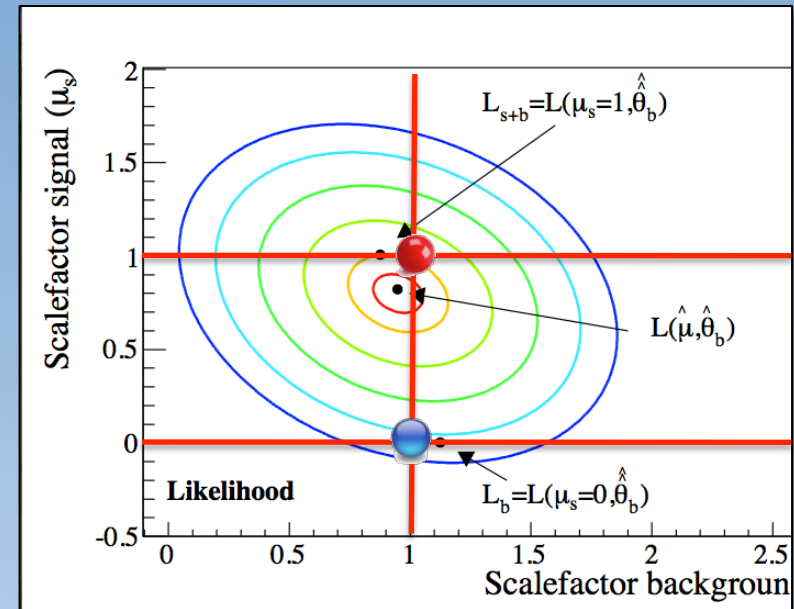
LHC experiments:

$$X(\mu) = -2\ln(Q(\mu)), \text{ with } Q(\mu) = \frac{L(\mu, \hat{\theta}(\mu))}{L(\hat{\mu}, \hat{\theta})}$$

**Note:**

$\alpha_{\text{bgr}}$  is just one of the nuisance parameters  $\theta$  in a 'real' analysis

*2-dimensional fit ( $\alpha$  and  $\mu$  free)*



Let's stick to counting but make it a bit more realistic

In real life:

- you do not know the background level with absolute precision
- What is the best estimate and what is its uncertainty ?

→ and how does it change your sensitivity ?

# Statistics

## 1) Measurement:

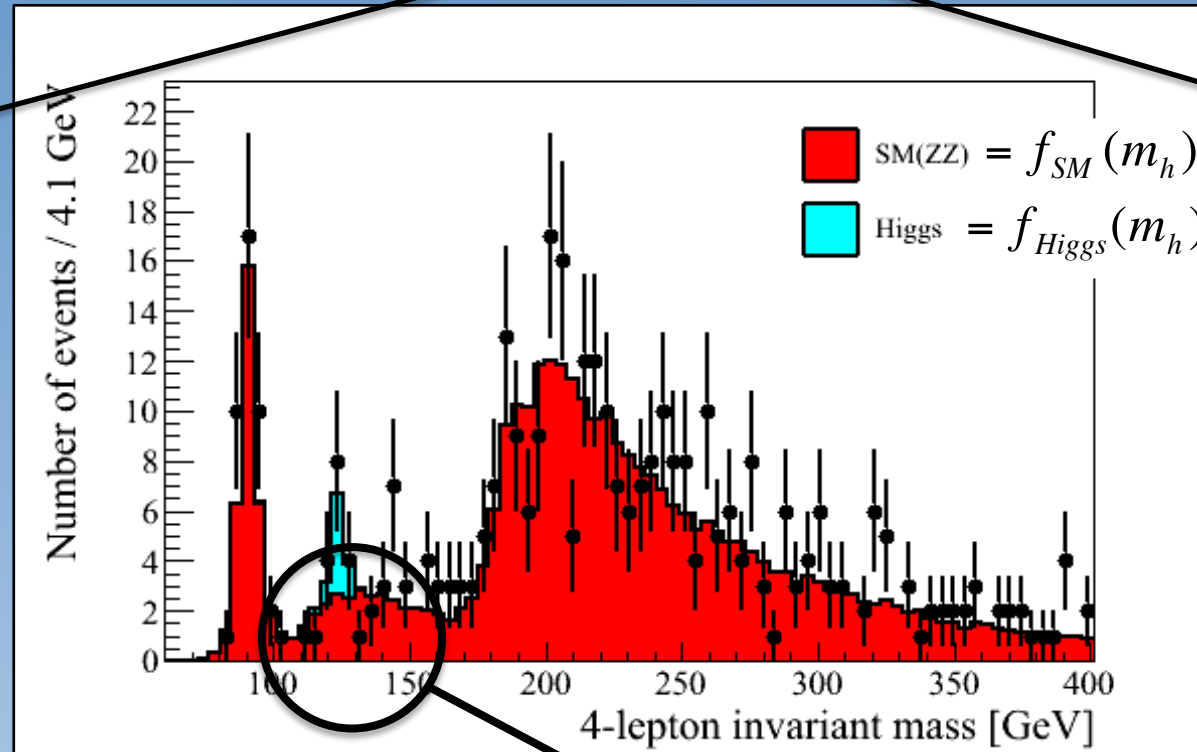
- *Likelihood fit*

## 2) Hypotheses testing & search:

- *Significance (definition and optimization)*
- *Test-statistic & pseudo-experiments (toy-MC)*
- *Exclusion/discovery*

Marumi:  $f(m_h) = \mu \times f_{\text{Higgs}}(m_h) + \alpha \times f_{\text{SM}}(m_h)$

Scale factor of  
the Higgs



Scale factor for  
background

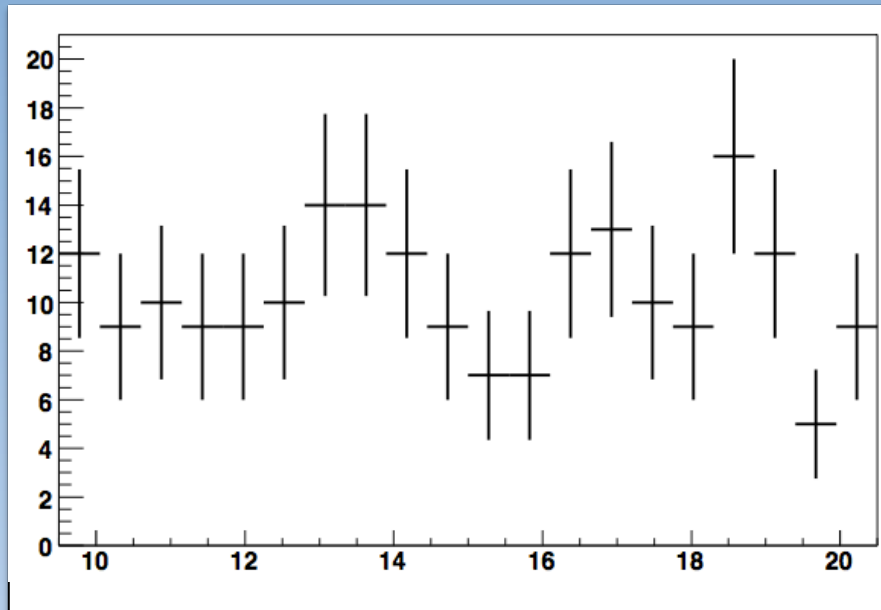
Goal: best background estimate:  $N_{\text{SM}} \pm \Delta_{\text{NSM}}$  ?

- 1) Estimate  $\alpha \pm \Delta\alpha$  in a background dominated region ( $m_h > 200$ )
- 2) Correct the MC estimate in signal region (from  $\alpha$ )
- 3) Compute uncertainty on the background level (from  $\Delta\alpha$ )

# Exercise 0

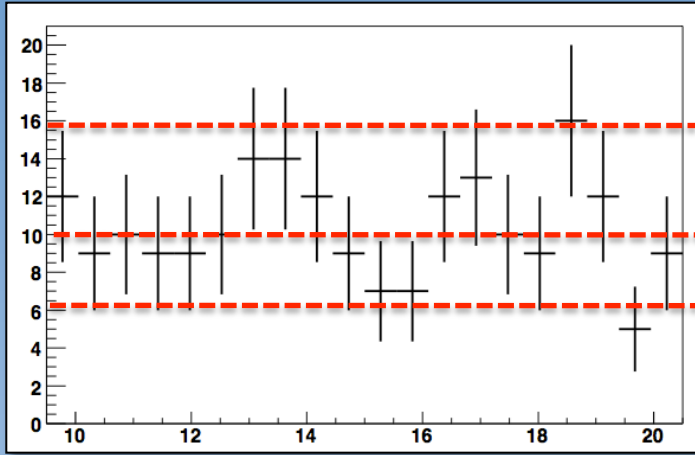
Produce a histogram on the screen

**Exercise 0: reproduce this histogram on your screen, compute mean and create a gif file. Add text if you like.**



**Note:** Look at the example macro's: Histogram\_Example\_0\*.C (\*=0,1,2,3,4,5)

## Fitting in 1 slide

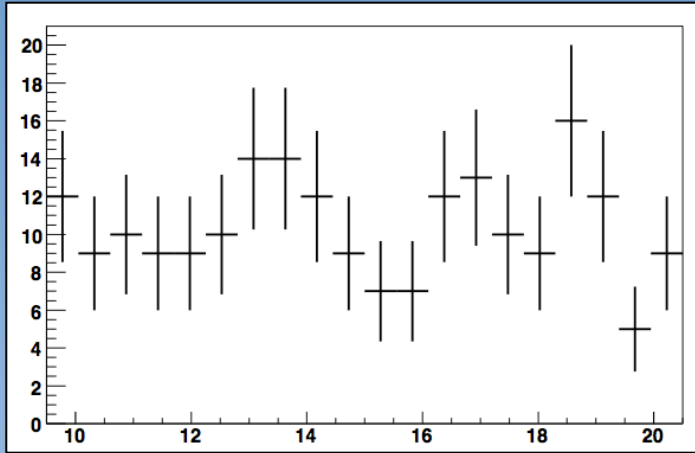


Your model:  $f(x) = \lambda$

Try different values of  $\lambda$   
and for each one compute:



# Fitting in 1 slide



You model:  $f(x) = \lambda$

Try different values of  $\lambda$  and for each one compute the **compatibility** of the model with the data

## $\chi^2$ -fit

**Compatibility number :**

$$\chi^2 = \sum_{bins} \frac{(N_{bin}^{data} - \lambda_{bin}^{expected})^2}{N_{bin}^{data}}$$

**Best value:**

Value of  $\lambda$  that minimizes  $\chi^2$  ( $\chi_{min}^2$ )

**Errors:**

Values of  $\lambda$  for which  $\chi^2 = \chi_{min}^2 + 1$

## Likelihood-fit

**Compatibility number :**

$$-2\log(L) = -2 \cdot \sum_{bins} \log(\text{Poisson}(N_{bin}^{data} | \lambda))$$

`TMath::Poisson( Nevt_bin,  $\lambda$  )`

**Best value:**

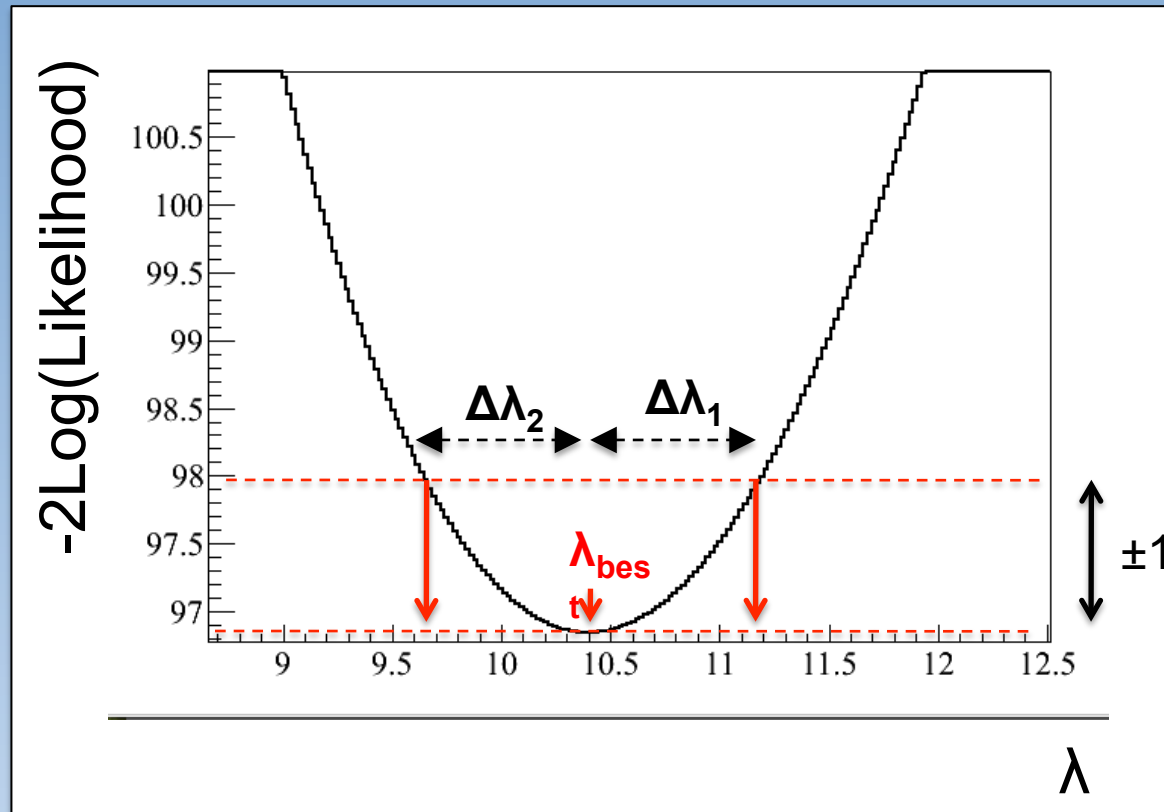
Value of  $\lambda$  that minimizes  $-2\log(L)$  ( $-2\log(L)_{min}$ )

**Errors:**

Values of  $\lambda$  for which  $2\log(L) = (-2\log(L)_{min}) + 1$

# Result from the fit

$$\text{result : } \lambda = \lambda_{\text{best}}^{+\Delta\lambda_1}_{-\Delta\lambda_2}$$



Link to Lecture or d'Agostini on Monday

Probability (data| $\lambda$ )

$\neq$

Probability( $\lambda$ |data)

What we have computed

*Likelihood*

What we want

# The Poisson distribution

Binomial with  $n \rightarrow \infty$ ,  $p \rightarrow 0$  and  $np = \lambda$

$$P(n | \lambda) = \frac{\lambda^n e^{-\lambda}}{n!}$$

*Poisson distribution*

Probability to observe  $n$  events  
when  $\lambda$  are expected

$$P(0 | 4.0) = 0.01832$$

$$P(2 | 4.0) = 0.14653 \quad !$$

$$P(3 | 4.0) = 0.19537$$

$$P(4 | 4.0) = 0.19537$$

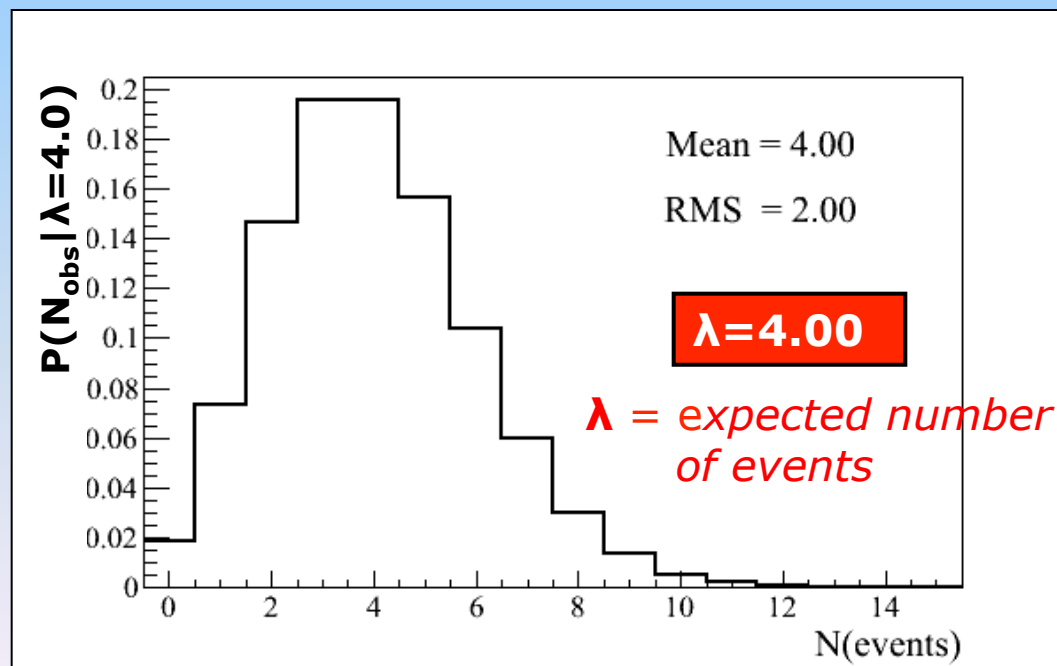
$$P(6 | 4.0) = 0.10420 \quad !$$

#observed

varying

$\lambda$  hypothesis

fixed



# Known $\lambda$ (Poisson)

Binomial with  $n \rightarrow \infty$ ,  $p \rightarrow 0$   $np = \lambda$

$$P(n | \lambda) = \frac{\lambda^n e^{-\lambda}}{n!}$$

*Poisson distribution*

Probability to observe  $n$  events  
when  $\lambda$  are expected

$$P(0 | 4.9) = 0.00745$$

$$P(2 | 4.9) = 0.08940$$

$$P(3 | 4.9) = 0.14601$$

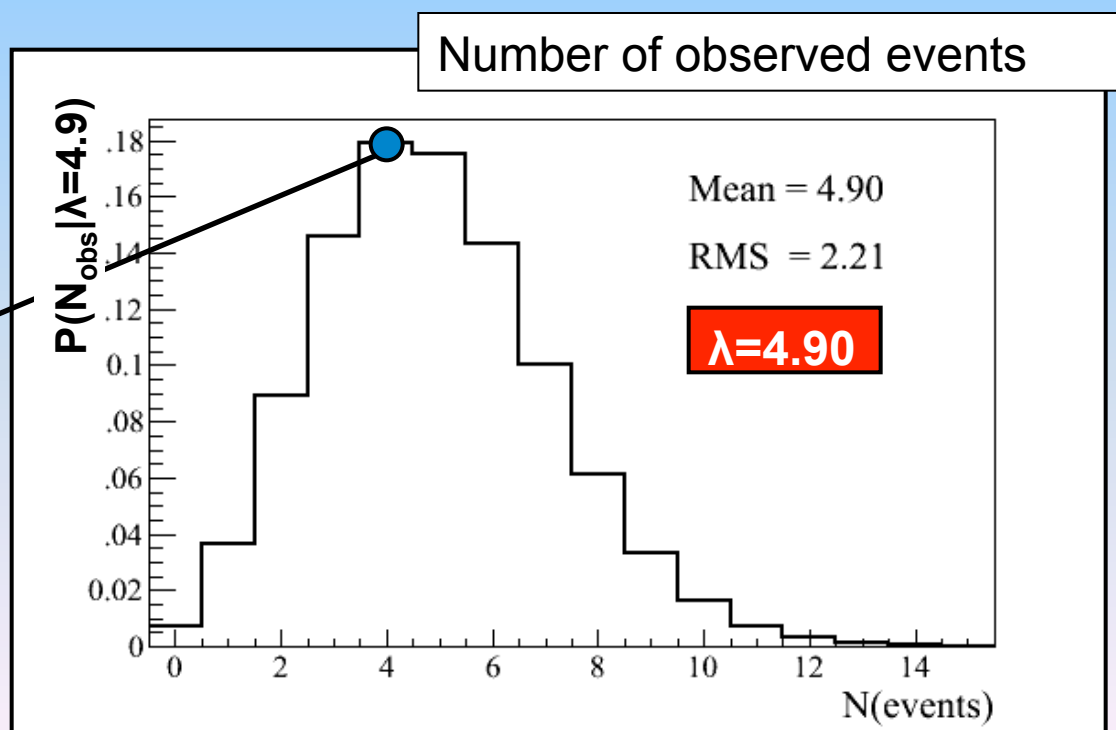
$$P(4 | 4.9) = 0.17887$$

#observed

**varying**

$\lambda$  hypothesis

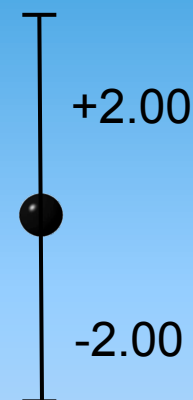
**fixed**



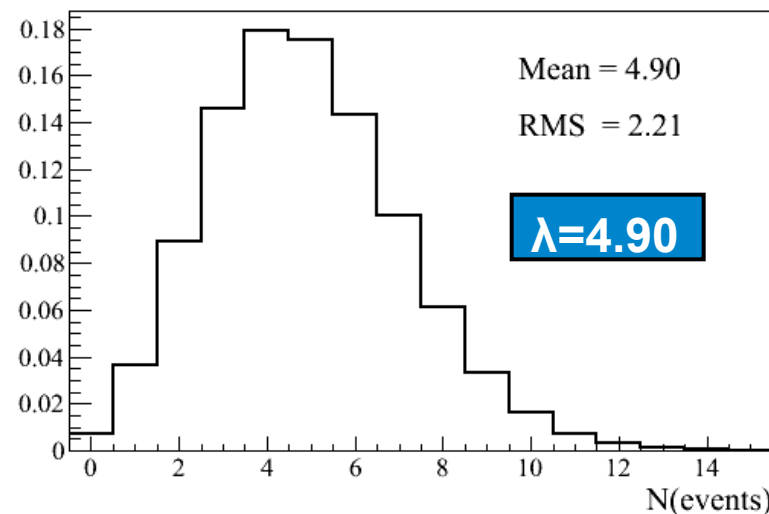
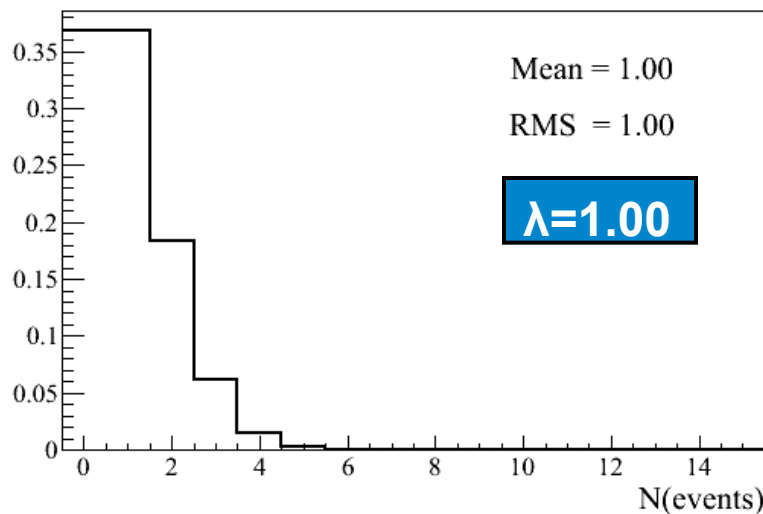
the famous  $\sqrt{N}$ **properties**

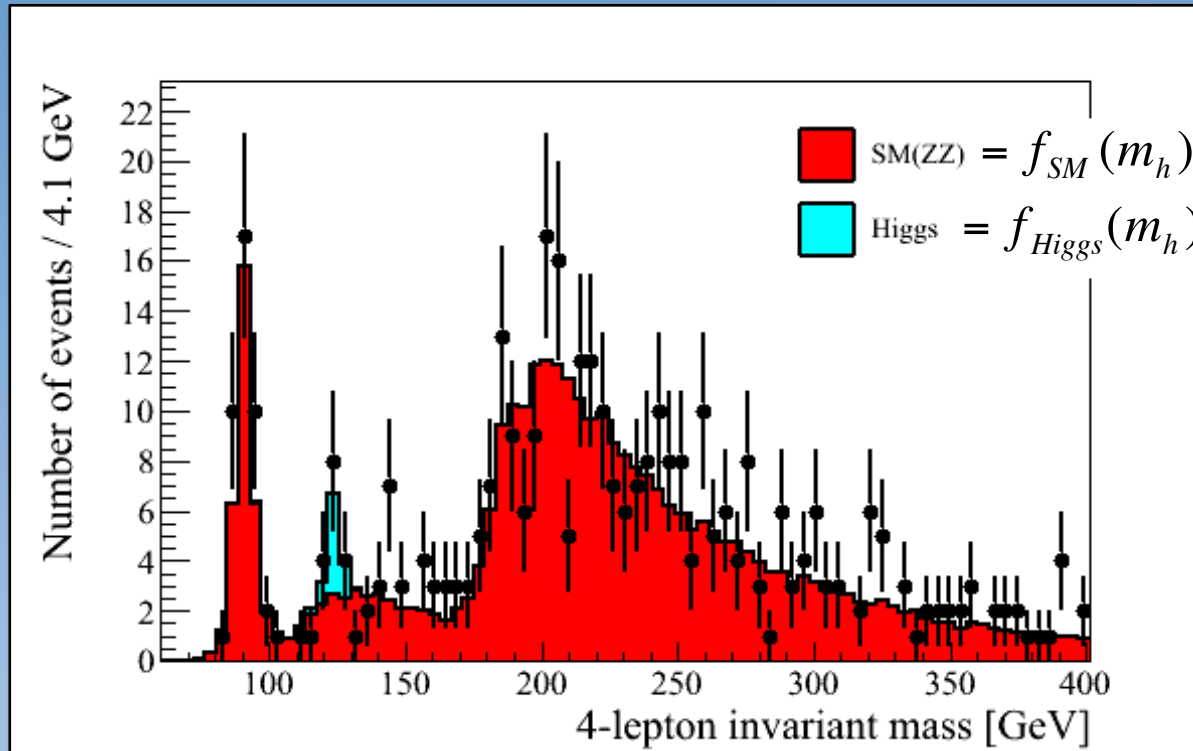
- (1) Mean:  $\langle n \rangle = \lambda$
- (2) Variance:  $\langle (n - \langle n \rangle)^2 \rangle = \lambda$
- (3) Most likely: first integer  $\leq \lambda$

Usual way to represent the error on a data-point



Not default in Root





$$f(m_h) = \mu \times f_{Higgs}(m_h) + \alpha \times f_{SM}(m_h)$$

Scale factor for the Higgs

EXERCISE 2

Scale factor for the SM background

EXERCISE 1

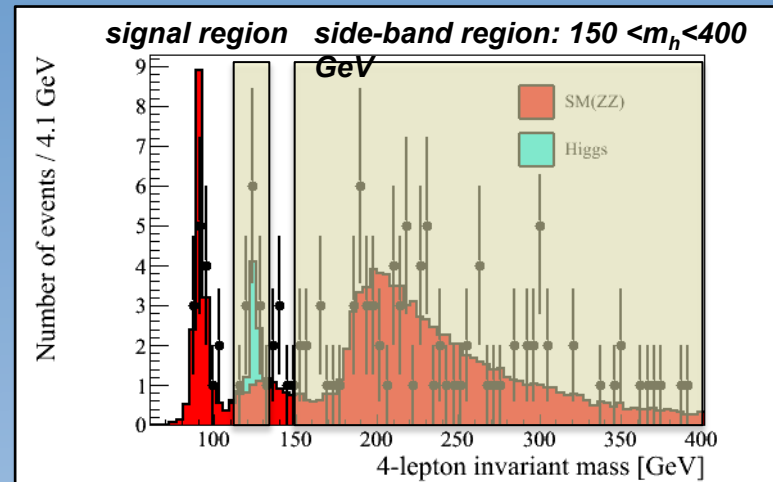


# Exercise 1

Data-driven background estimate in a  
10 GeV mass window around 125 GeV

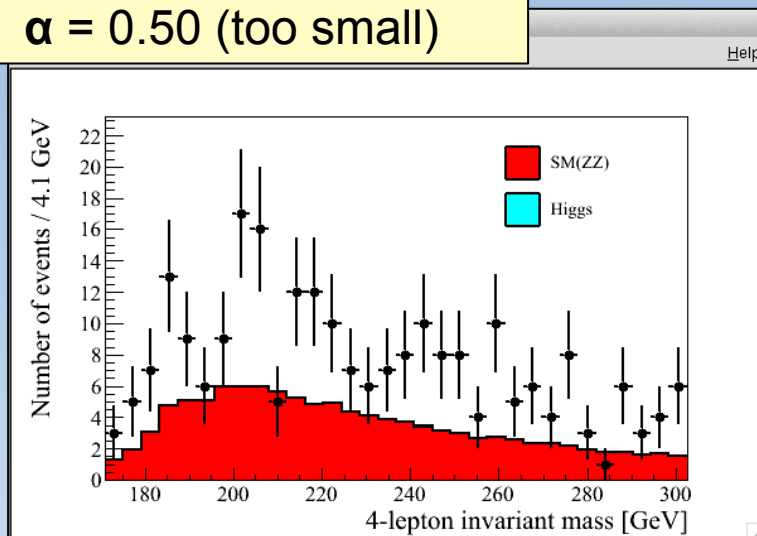
Code you could use:

```
SideBandFit()
```

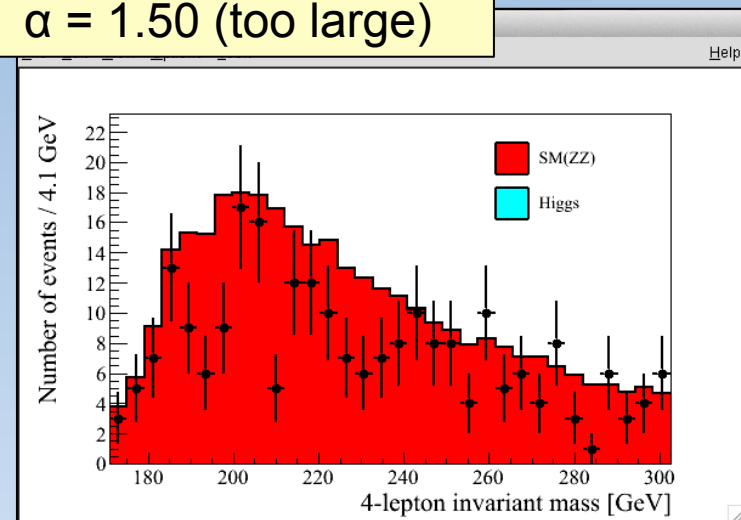


**Exercise 1: determine the best estimate for the background scale factor ( $\alpha$ ) by doing a fit in the side-band region  $175 \leq m_h \leq 300$  GeV (later  $150 \leq m_h \leq 400$  GeV)**

$\alpha = 0.50$  (too small)



$\alpha = 1.50$  (too large)



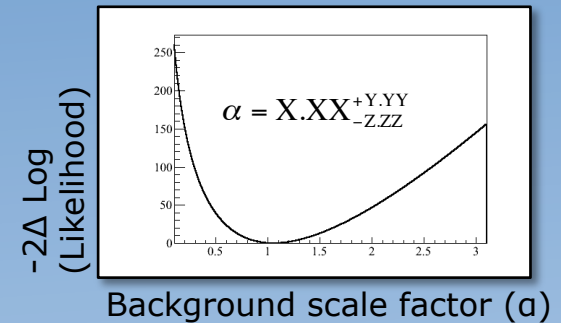
## Exercise 1: determine the best estimate for the background scale factor factor ( $\alpha$ ) using a fit in a side-band region $175 \leq m_h \leq 300$ GeV

### 1.1 Find the best value $\alpha$ for using a **likelihood fit**

#### Computing the likelihood:

For each 'guess' of  $\alpha$ :

$$-2\log(L) = -2 \cdot \sum_{bins} \log(\text{Poisson}(N_{bin}^{data} | \alpha \cdot f_{bin}^{SM}))$$



Background scale factor ( $\alpha$ )

### 1.2 Find the best value $\alpha$ for using a **$\chi^2$ fit**

$$\chi^2 = \sum_{bins} \frac{(N_{bin}^{data} - \lambda_{bin}^{expected})^2}{N_{bin}^{data}}$$

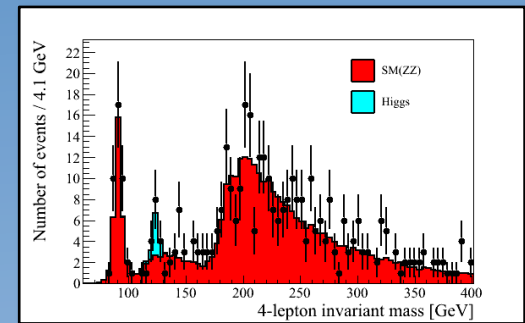
*Wikipedia: Carl Friedrich Gauss is credited with developing the fundamentals of the basis for least-squares in 1795 at the age of 18. Legendre was the first to publish the method however.*

### 1.3 Discuss the differences between the two estimates

### 1.4 Redo 1.1 and 1.2 with $150 \leq m_h \leq 400$ GeV. What happens ?

### 1.5 Use the likelihood fit, fine binning and $150 \leq m_h \leq 400$ GeV to determine the best estimate for $\alpha$ ( $\alpha_{best} \pm \Delta\alpha$ ). Estimate the bckg level ( $b \pm \Delta b$ ) in the signal region: $120 \leq m_h \leq 130$ GeV

# Exercise 3



**Exercise 3.5: How does the uncertainty on the background change the observed and expected significance ?**

Use toy-Monte Carlo experiments (numbers or distributions)

# Basic material for the Root examples:

- 1) Download tarball: **HascoRootStatisticsCode.tgz**
- 2) Unpack everything: **tar -vzxf HascoRootStatisticsCode.tgz**

## Directory /RootExamples/

- |   |                                    |
|---|------------------------------------|
| a) Example0*.C (* = 0,1,2,3,4,5)          | All *.C-files in this presentation |
| b) Code for Ntuple production and reading |                                    |
| c) rootlogon.C                            | some standard Root settings        |


## Directory /Exercises/

- |   |  |
|---|--|
| a) Histograms_fake.root   |  |
| 4 histograms of the 4-lepton invariant mass (H125, H200, ZZ, data)    |  |
| b) Hasco_skeleton.C   |  |
| skeleton code (different levels, as minimal as possible). Your code ! |  |
| c) rootlogon.C  |  |
| some standard Root settings   |  |





Exercises

A person is captured mid-air, performing a backflip into a calm body of water. The person is upside down, with their arms and legs tucked. The water is still, reflecting the sky and the distant shoreline. The shoreline is visible in the background, featuring some trees and a fence. The overall scene is peaceful and serene.

Good luck

Questions/remarks:

[Ivo.van.Vulpen@nikhef.nl](mailto:Ivo.van.Vulpen@nikhef.nl)

BACKUP



# Exercise 4

compute test-statistic  $X$

$$X = -2\ln(Q), \text{ with } Q = \frac{L(\mu_s = 1)}{L(\mu_s = 0)} \begin{array}{l} \longrightarrow \text{Likelihood assuming } \mu_s=1 \text{ (signal+background)} \\ \longrightarrow \text{Likelihood assuming } \mu_s=0 \text{ (only background)} \end{array}$$

## Exercise 4: create the likelihood ratio test statistic – beyond simple counting

**4.1** Write a routine that computes the likelihood ratio test-statistic for a given data-set

`double Get_TestStatistic(TH1D *h_mass_dataset, TH1D *h_template_bgr, TH1D *h_template_sig)`

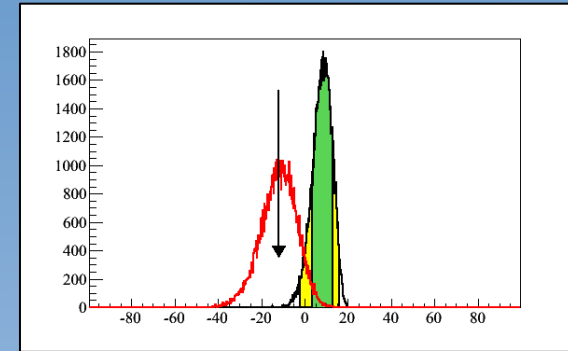
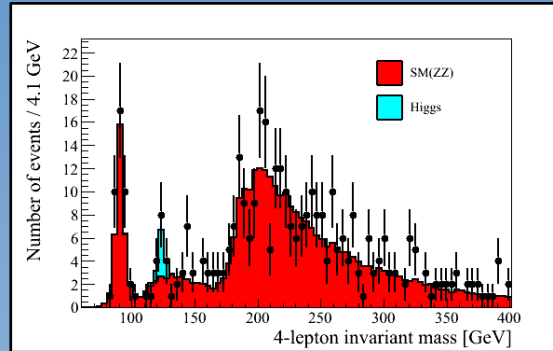
$$-2\text{Log}(\text{Likelihood}_{(\mu, \alpha = 1)}) = -2 \cdot \sum_{bins} \log\left(\text{Poisson}(N_{bin}^{data} \mid \mu \cdot f_{bin}^{Higgs} + \alpha \cdot f_{bin}^{SM})\right)$$

**Note:**  $\log(a/b) = \log(a) - \log(b)$

**4.2** Compute the likelihood ratio test-statistic for the 'real' data

# Exercise 5

## Toy data-sets



### Exercise 5: create toy data-sets

**5.1** Write a routine that generates a toy data-set from a MC template (b or s+b)

**TH1D \* GenerateToyDataSet(TH1D \*h\_mass\_template)**

How: Take the histogram h\_mass\_template and draw a Poisson random number in each bin using the bin content in h\_mass\_template as the central value. Return the new fake data-set.

**5.2** Generate 1000 toy data-sets for *background-only* & compute test statistic  
Generate 1000 toy data-sets for *signal+background* & compute test statistic  
→ plot both in one plot

**5.3** Add the test-statistic from the data(exercise 4.2) to the plot

# Exercise 6

Summarize separation power

## Exercise 6: compute p-value

- 6.1** Compute the p-value or  $1-Cl_b$  (under the background-only hypothesis):
- For the average(median) b-only experiment
  - For the average(median) s+b-only experiment [expected significance]
  - For the data [observed significance]
- 6.2** Draw conclusions:
- Can you claim a discovery ?
  - Did you expect to make a discovery ?
  - At what luminosity do you expect to be able to make a discovery ?

# Exercise 7:

Exclude a cross-section for a given Higgs boson mass

Some shortcomings,  
but we'll use it anyway



$$\sigma_h(m_h) = \xi \cdot \sigma_h^{SM}(m_h)$$

↓  
scale factor wrt SM prediction

## Exercise 7: compute $CL_{s+b}$ and exclude Higgs masses or cross-sections

### 7.1 Compute the $CL_{s+b}$ :

- For the average(median) s+b experiment
- For the average(median) b-only experiment
- For the data

### 7.2 Draw conclusions:

- Can you exclude  $m_h=200$  GeV hypothesis ? What  $\xi$  can you exclude ?
- Did you expect to be able to exclude the  $m_h=200$  GeV hypothesis ?  
What  $\xi$  did you expect to be able to exclude ?