Instructions for tutors

1. Name of the measurement: Z-Path

2. Authors: Maiken Pedersen, Farid Ould-Saada, Eirik Gramstad, Magnar Bugge, Vanja Morisbak, Silje Raddum

3. Supported languages: Czech, Danish, English, French, German, Greek, Italian, Norwegian, Polish, Portuguese, Slovak, Spanish and Turkish

4. Short description of measurement
- Use of HYPATIA event display and categorisation of events as di-electrons, di-muons, di-photons or 4-leptons
- Building and plotting of invariant mass of the various particle combinations (OPloT https://zpathweb.hepp.uiocloud.no/)
- Identification of short-lived particles (Z, J/Psi, Upsilon) and search for the Higgs boson (H) and other exotic particles (Z', Graviton)
- Measurement of mass (when possible) and comparison with experiment

5. Prerequisites (Browser, Software...):
- Reliable, high-speed internet connection
- HYPATIA requires up-to-date version of Java. Versions 7 (preferred) and 6 are supported
- Tell the students to download HYPATIA and Java before the masterclass if they are going to use their own laptops

How to start HYPATIA
- HYPATIA can be accessed from the Z-path: http://atlas.physicsmasterclasses.org/en/zpath_data.htm or more directly from: http://hypatia.phys.uoa.gr/Downloads/HYPATIA/Hypatia_7.4_Masterclass.zip
1. Download
2. Unzip it onto your Desktop
3. To start HYPATIA:
   a. Navigate to the HYPATIA folder you downloaded
   b. On Windows and Mac:
      - Double click on "Hypatia_7.4_Masterclass.jar"
   c. On Linux:
      - Right click on "HYPATIA_for_Linux.sh" and change permissions so that it is executable
      - Double-click on "HYPATIA_for_Linux.sh"
      - If this does not work, use a terminal and issue the command 'java -jar Hypatia_7.4_Masterclass.jar' inside the Hypatia directory

OPloT technicalities
- **Testing student-style upload of results**:
    - If you want to test this beforehand, you can try to upload some test-files (already analysed test-data from HYPATIA) from here:
    - http://cernmasterclass.uio.no/datasets/testfiles/Invariant_Masses.txt
    - Try uploading them to one of the *Test-Institutes* from the same drop-down box as described for the students in the main OPloT section.
    - Test-date is January 01 2016, chose any *Test-Institute* you like
- **If you need to delete a student's upload**, you can do this from the Administrator tab.
    - The student can only upload one file. If there was a mistake, you will need to delete the file, before a new upload can be done.
    - You will need to know the particular dataset of that student to identify correctly the file to be removed
    - To log into the administrator pages:
        - ask epf-mc@fys.uio.no for password
- **If case of bad internet connection**
    - If students in general do not have internet connection – and you as instructor need to upload the results, you can collect all the students' results, and copy and paste all results into 1 single file that you can upload to the web-tool, following the instructions on how to upload to OPloT in the main OPloT instructions. Just chose any group you want from your Institute, as there will only be 1 single file.

6. Datasets: ATLAS real pp-data from 2012 at 8 TeV + MC simulations
- Di-leptons: ~20000 events from data
    - Di-electrons and di-muons from Z (mainly), J/psi and Upsilon
    - 2000 fully simulated Z' events (mass 1 TeV), equally shared among the e^+e^- and $\mu^+\mu^-$ decay channels
    - 600 fully simulated Graviton events (mass 1.5 TeV), equally shared among the e^+e^- and $\mu^+\mu^-$ decay channels
- Di-photons: Higgs candidates (data) and simulated Gravitons
    - Higgs candidates: real data events corresponding to 2 fb^{-1}
        - ~10000 events
        - $\gamma\gamma$ cuts as in ATLAS publication – including converted photons,
    - ~400 fully simulated Graviton events (mass 1.5 TeV) decaying into di-photons
- 4 leptons: Higgs candidates (data) and simulated Gravitons
    - Higgs candidates: 40 events
        - cuts as in ATLAS publication
    - ~400 fully simulated Graviton events (mass 1.5 TeV) decaying into two Z-bosons (which subsequently decay into electrons and muons)
- Dataset location
    - The institute's dataset-number is to be found at this location:

http://cernmasterclass.uio.no/datasets/
- o The dataset contains a certain number of groups of data. Each group of 50 events is to be assigned to and analysed by 2 students working together.

7. Proposed outline for the day
- 09:45 – 10:00 Arrival & Welcome
- 10:00 – 12:00 Lectures (twice 45 minutes + time of questions & discussion)
  - o Introduction to particle physics with emphasis on LHC and Higgs observation
  - o Introduction to detectors and particle identification
- 12:00-13:00 Lunch
- 13:00 – 13:45 Introduction to the measurement
  - o Invariant mass technique and identification of short-lived particles
  - o Decays of Z-boson and Higgs
  - o Event categorisation – detailed examples
- 13:45 – 15:15 Measurements
- 15:15 – 15:30 Break
- 15:30 – 16:00 Discussion of results & preparation for video-conference
- 16:00 – 17:00 Video-conference

8. Students´ tasks

Instructions for analysis, and download links
- Tally sheets, HYPATIA, link to OPloT are to be found at this location: http://atlas.physicsmasterclasses.org/en/zpath_data.htm
- The tutors show on a screen the following steps and make sure that all students follow the steps simultaneously such that no time is wasted before the start of the analysis.
    1. HYPATIA running
    2. Know which dataset to analyse (see "Datasets" above)
    3. Tally-sheet in front of them
        a. Before analysis starts, assign each group of 2 students to a data group (identified by a letter and a number). This name will correspond to the file of events they will be analysing.
        b. Give each group of students the tally sheet corresponding to their assigned letter and number – Get it from the web (linked from the zpath_data.htm page): http://cernmasterclass.uio.no/2014/material/tallysheet/

NB: As OploT keeps track of what kind of events the students have seen, one can choose not to distribute tally sheets, but then the dataset number/letter must be distributed to the student by other means.

    4. Have opened the plot-submission page (OPloT: https://zpathweb.hepp.uiocloud.no/OPloT/index.php)

9. How they do it (step by step)
- What to do, step by step
    1. In HYPATIA, for each collision, try to find signs of the existence of

particles such as
  a. a Z boson, J/Psi, Upsilon, Graviton or Z', by hunting for an electron-positron pair or a muon-antimuon pair,
  b. a Higgs boson or Graviton by hunting for a photon-photon pair
  c. a Higgs boson or Graviton by hunting for 2 lepton-pairs ($e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$, $\mu^+\mu^-\mu^+\mu^-$)
2. Use the pointing tools and particle information in HYPATIA to make your decision.
3. If you believe you see the decay-products of one of the particles above, pick the corresponding tracks or objects and insert them into the HYPATIA invariant mass table.
  a. If you find a pair of electron- or a pair of muon-tracks you might have found a Z boson or the much lighter J/Psi or Upsilon particle.
  b. If you are lucky to see 2 pairs of leptons, insert them both; you may have a Higgs candidate decaying to 4 leptons!
  c. If you believe you see a candidate Higgs boson decaying to a pair of photons, pick both photons and insert them into the HYPATIA invariant mass table. Some examples with one or two converted photons are described in an accompanying document. It is explained how to deal with events where one or 2 tracks point to the electromagnetic cluster. A pair of e+e- with an invariant mass very close to 0 can safely be considered as coming from a converted photon.
4. If you cannot categorize the event into any of the categories above write down the event number and go back later (or ask a tutor).
5. After analysing all events, export the *Invariant Mass Table* from HYPATIA: File->Export Invariant Masses.
  a. The file is called "Invariant_Masses.txt" by default (do not change it). Place the file on your Desktop so you can easily find it.
6. Go to the OPloT page https://zpathweb.hepp.uiocloud.no/OPloT/index.php (see **point 10** below for instructions).

- **Some selection recommendations**
  o See document http://cernmasterclass.uio.no/material/Zpath-Cuts.pdf

10. Gaining and presentation of results
- Students proceed with the uploading of the invariant mass table "Invariant_Masses.txt" here https://zpathweb.hepp.uiocloud.no/OPloT/index.php following the steps (see also screen shot below):
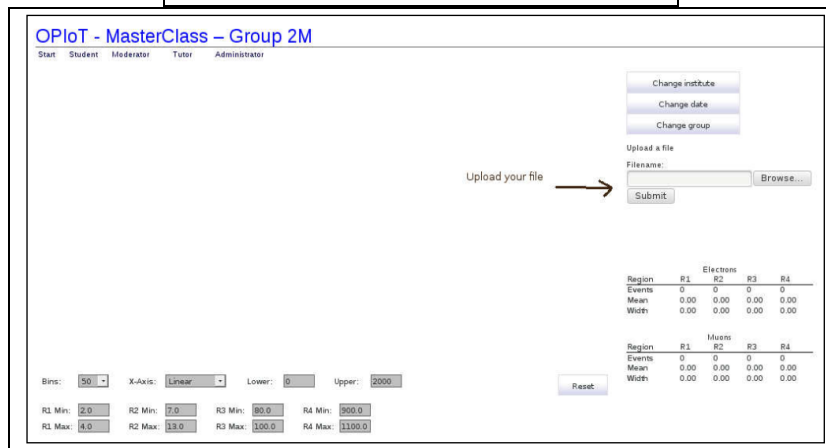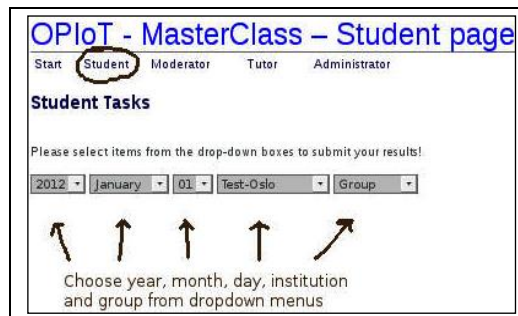 1. Students select "Student" menu-item
* username: ippog
* password: imc
  2. Students select correct date and institute from drop-down menu

3. Students select their correct group from a drop-down menu
4. Students upload the file "Invariant_Masses.txt" they have made

With OPloT you have the possibility to choose the set of invariant mass plots you'd like: all three, any 2 or 1. Here the "ll" distribution is chosen together with arrows pointing to parameters you can change.
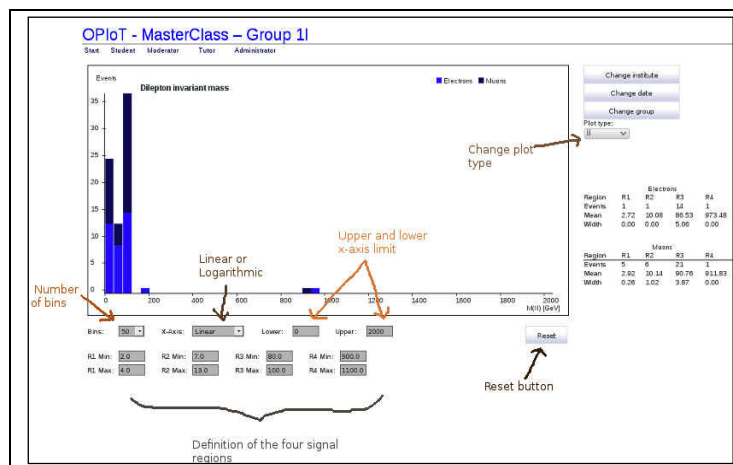
11. What can be discussed (proposed questions)

- **di-lepton measurement**
  - Compare the histograms of the electron-positron and muon-antimuon pairs.
    - o Can you point out differences/similarities?
    - o How often does the Z boson decay into electron-positron pairs? How often does the decay result in muon-antimuon pairs?
    - o What did you expect? Why?
    - o Do you notice any other particles? At which invariant masses?
  - What is the most probable mass of the Z boson?

- o Why is there not one exact value for the Z boson mass?
  - o What could be the possible explanations of why the distribution is so wide?
- Have you discovered the Z' boson?
  - o If you think so, what is the Z' boson's mass?
- Have you discovered the Graviton?
  - o If you think so, what is the Graviton mass?
- Why is it useful to combine your results with those obtained by other groups?

- **di-photon measurement**
  - Do you see any sign of Higgs decaying to 2 photons, H→γγ?
    - o If not, what could be the reasons?
    - o In fact the full sample does contain real Higgs candidates, even if you have not found them!
  - Any sign of the Z' boson or Graviton?
    - o Why/why not?
- **4-lepton measurement**
  - Do you see any sign of Higgs decaying to 4 leptons, H→ZZ→llll?
    - o If not, what could be the reasons?
  - In fact the whole sample contains Higgs candidates. At which mass?
  - Any sign of the Z' boson or Graviton?
    - o Why/why not?

12. For tutors: Details on combination and discussion

It is very important that the (at the institute level combined) results are already discussed before the video-conference. The video-conference this year will be very brief when it comes to physics-discussion, and the students should already be aware of the important points when it comes to their invariant mass plots and possible interpretations.

- Go to the plot-submission page:
  https://zpathweb.hepp.uiocloud.no/OPloT/index.php
- Click on the "Tutors" menu-item
- Choose the right year-month-day in the three drop-down menus
- Click on your institute under "Institute combination"
- A set of plots will appear, which is the combination of all your students results
- Click on "*Slides - comparing IMC data with official ATLAS Results*" on the Tutor page in OPloT for a comparison with official ATLAS results

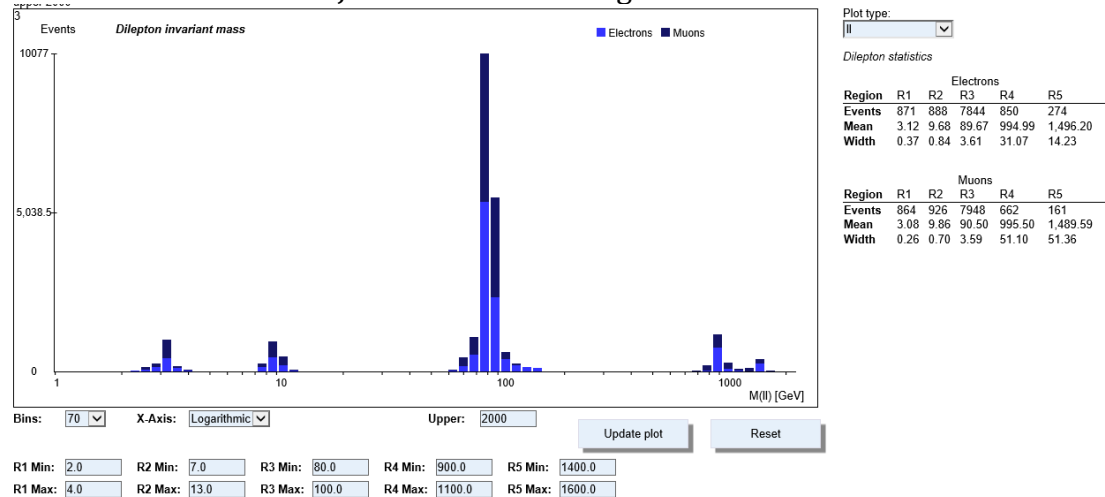The screen shots of section 10 remind how to proceed with OPloT.

In the following, some examples of combined plots obtained with a small sample of events are commented. *Tutors at the institute level will have access to combined plots with more statistics.*

The figure below shows the 3 invariant mass distributions ("ll+4l+γγ" chosen as "Plot type"). Number of bins and lower/upper values of x-axis can be changed.

There will be a possibility for a summary plot including a full mass range (in logarithmic scale) of the di-lepton distribution, as well as summary plot for the Higgs distributions.
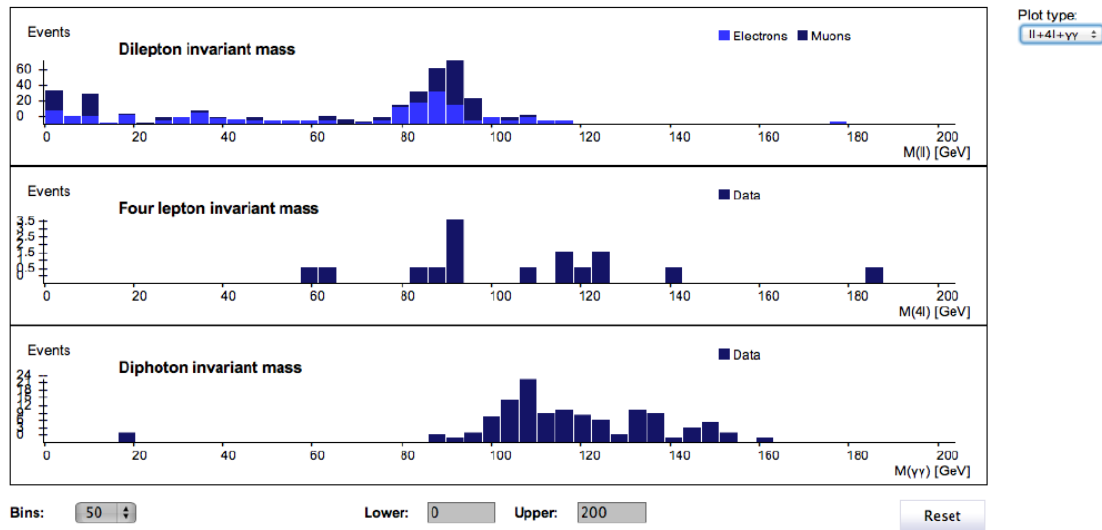

In the figure below, only the "ll" type is chosen. Note that logarithm scale is used for the x-axis in order to clearly see 4 resonances simultaneously: J/ψ (~3 GeV), Υ(~10 GeV), Z(~90 GeV), Z'(~1000 GeV) and Graviton (~1500 GeV). The table to the right summarises the results (mass and width) of the 5 particles corresponding to the 5 regions R1-5. Final states with electrons (upper) and with muons (lower) can be compared. It is worth noticing that the Z' and G distributions are wider for muons than for electrons. This is due to the fact that the muon mass resolution, obtained using the tracking detectors, worsens the higher the energy, contrary to the electrons measured by the electromagnetic calorimeter. At low energies the effect is negligible as demonstrated by the Z and lower mass resonances. Just in case some bright student asks!


Dilepton statistics

		Electrons			
Region	R1	R2	R3	R4	R5
Events	871	888	7844	850	274
Mean	3.12	9.68	89.67	994.99	1,496.20
Width	0.37	0.84	3.61	31.07	14.23

		Muons			
Region	R1	R2	R3	R4	R5
Events	864	926	7948	662	161
Mean	3.08	9.86	90.50	995.50	1,489.59
Width	0.26	0.70	3.59	51.10	51.36

Next, the invariant mass of 4 leptons is shown below – plot type "4l" chosen. In addition to the "student distribution", two coloured "Higg MC" distributions are added for two luminosities (10fb[-1] and 25 fb[-1]), showing how many Higgs events are expected assuming the Higgs mass to be 125 GeV. A comment: there are too few 4-lepton events and identical events are analysed by many students. In the combination 4-lepton plots, however, the duplicates are removed.
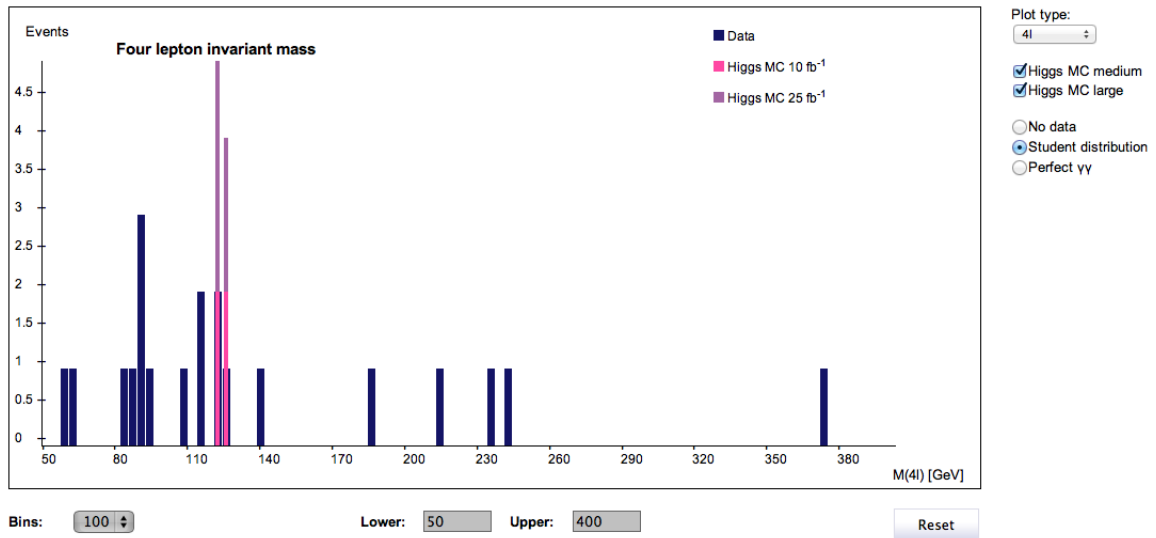
To reveal the Graviton peak the "Lower" and "Upper" limit on the x-axis must be set to e.g. 700 and 2000 respectively, as shown in the plot below. The region "R" gives the statistics of the Graviton peak. Note that the "expected distribution" is only available in the Higgs mass-range
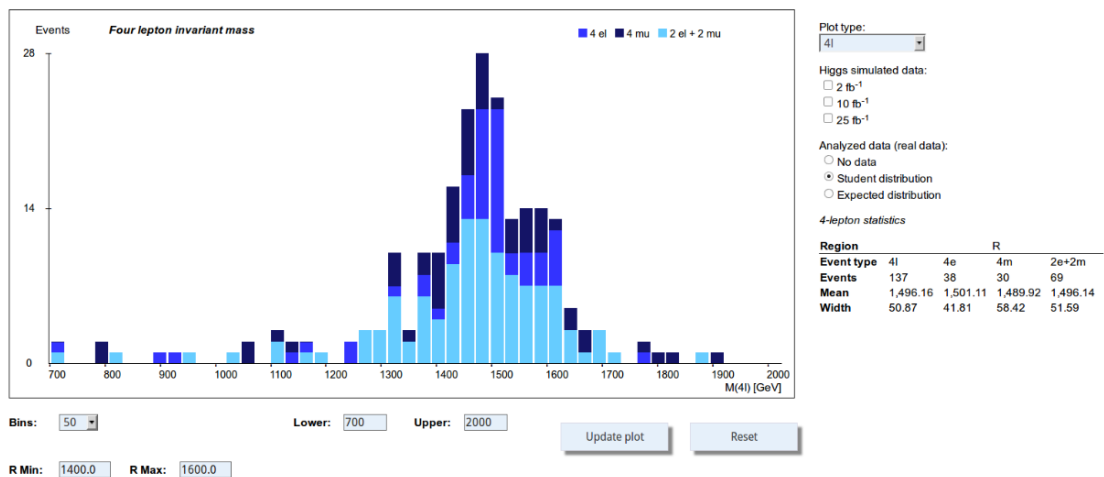
Finally, the invariant mass of 2 photons is given below – plot type "γγ" chosen. Data obtained by the students are in blue. The expected simulated background (green) and 125 GeV Higgs signal (pink-ish) is shown when the box "Signal and background 1fb⁻¹" is ticked. Note that if all γγ data had been used, the blue (student) distribution would be close to the green background MC. The goal of these comparisons is to show that given the high background, compared to the tiny Higgs signal, 1fb^{-1} of data is not enough to disentangle the signal from the background. More data is obviously needed before claiming a discovery.
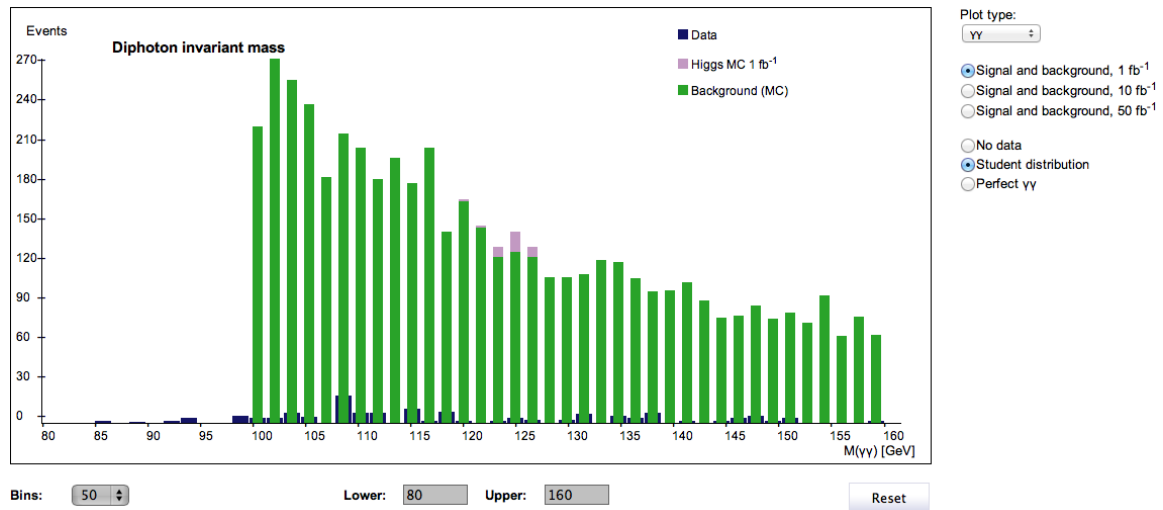
To claim discovery, ATLAS analysed more than 10fb^{-1} of data. The next figure demonstrates that with 50fb^{-1}, for example, a clear signal singles out on top of a smooth exponential background.
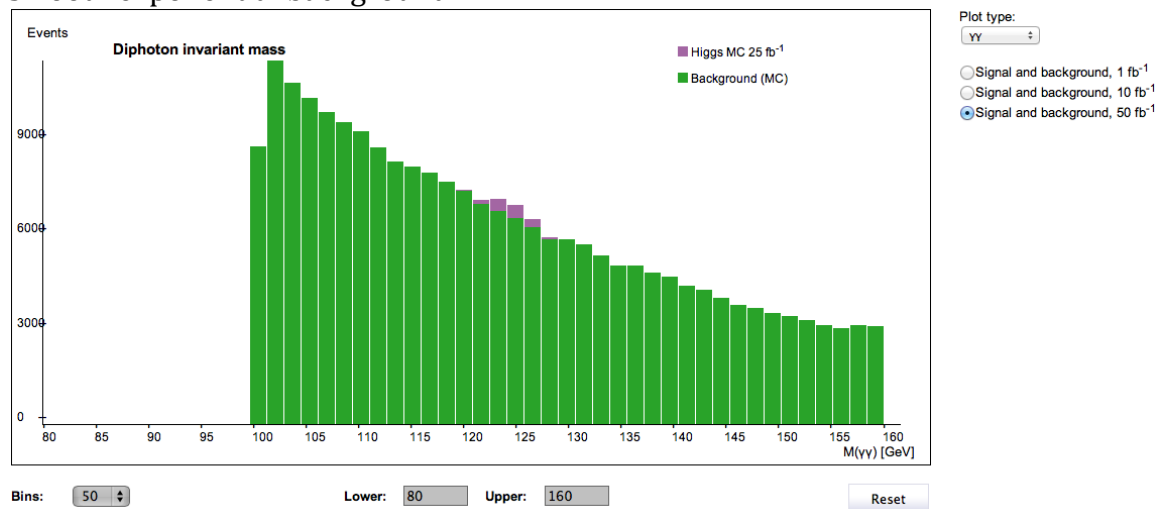
To get a better idea what to expect, you can take a look at last year's results in OPloT. This is also useful to familiarize yourself with the tool.

To see the Graviton peak the same exercise as in the "4L" view must be done (i.e set the x-axis limits to e.g. 1000-2000). The "R" region gives again the statistics for the Graviton peak.

13. Supporting material for students
- Cheat-sheet (http://cernmasterclass.uio.no/material/cheat-sheet_en.pdf)
  - help with particle identification
  - and get started – how to open HYPATIA, find datasets, load events, upload results to OPLOT and so on

14. Supporting material in general
- A couple of slides for the institute/moderator discussions (http://cernmasterclass.uio.no/material/Zpath-ATLAS.pdf)
- Some detailed examples of event categorisation

(http://cernmasterclass.uio.no/material/Zpath-SignalEvents.pdf)
- Introductory lectures I and II and *Introduction to Experiment*
  - In Norwegian (switch .ppt with .pdf if pdf-format is favoured)
    - About particle physics in general: http://cernmasterclass.uio.no/2015/osloweb/doc/MC-Oslo2015-IntroPartikkelfysikk.ppt
    - About detectors and particle identification: http://cernmasterclass.uio.no/2015/osloweb/doc/MC2015_Eirik.ppt
    - Specific introduction to excercises: http://cernmasterclass.uio.no/2015/osloweb/doc/MC-Oslo_2015-IntroTilEksperimentet.ppt
  - In English (will come)

More information can be found here: