

## Instructions for tutors / moderators

### 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, Portuguese, Slovak, Turkish

### 4. Short description

- Use of [HYPATIA](#) event display and categorise events according to di-electrons, di-muons, di-photons, 4-leptons
- Building and plotting of invariant mass of the various particle combinations ([OPLOT <http://cernmasterclass.uio.no>](#))
- Identification of short-lived particles (Z, Jpsi, Upsilon) and search for the Higgs boson and other exotic particle (Z')
- 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

### 6. Datasets: ATLAS real pp-data from 2011 at 7 TeV

- Di-leptons ~10000 events
  - Di-electrons and di-muons from Z (mainly), Jpsi and Upsilon
  - 1000 fully simulated Z' events (1TeV)
- Higgs candidates real data events corresponding to  $1\text{fb}^{-1}$  (period I,J,K)
  - Di-photon:  $\gamma\gamma$  cuts as in ATLAS pub – including converted photons
  - 4-leptons: cuts as in ATLAS pub – but omitting Z-requirement for leading pair and using lower  $p_T$  cut for sub-leading pair
  - Corresponding Higgs simulation of signal (125 GeV)
- Dataset location
  - The institute's dataset-number is to be found at this location: <http://cernmasterclass.uio.no/datasets/>
    - Username: ippog
    - Password: mc12
  - 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)
  - Introduction to particle physics with emphasis to LHC and Higgs-like observation

- Introduction to detectors and particle identification
- Lunch
- 13:00 – 13:45 Introduction to the measurement
  - Invariant mass technique and identification of short-lived particles
  - Decays of Z-boson and Higgs
  - Event categorisation – detailed examples
- 13:45 – 15:15 Measurement
- 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

- Tallysheets, HYPATIA, link to OPloT are to be found at this location: [http://atlas.physicsmasterclasses.org/en/zpath\\_data.htm](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 – Get it from the web (linked from the zpath\_data.htm page):  
<http://atlas.physicsmasterclasses.org/downloads/tallysheet Z.zip>
  4. Have opened the plot-submission page (OPloT <http://cernmasterclass.uio.no/OPloT> )

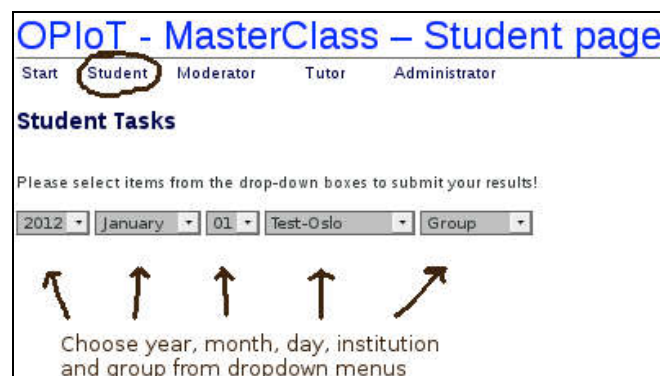
### 9. How they do it (step by step)

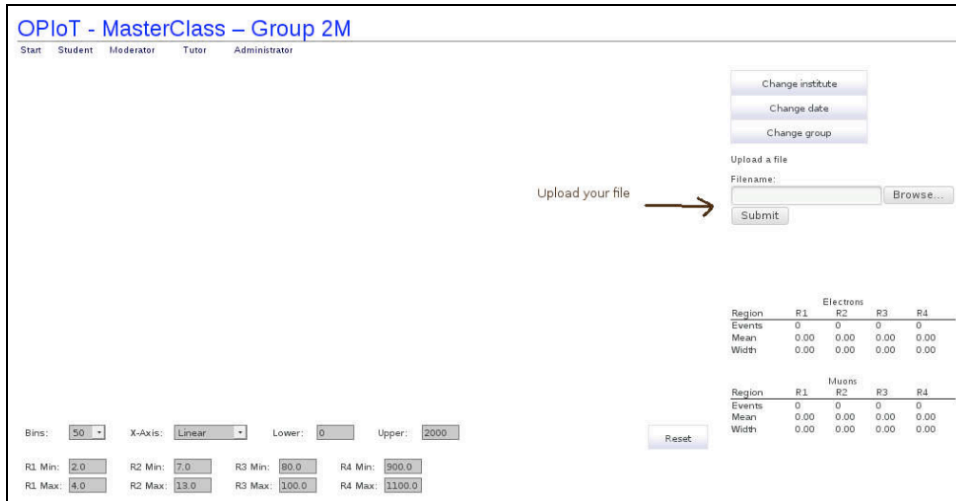
- What to do, step by step
  1. In HYPATIA, for each collision, try to find signs of the existence of particles such as
    - a. a Z boson, by hunting for an electron-positron pair or a muon-antimuon pair,
    - b. a Higgs boson by hunting for a photon-photon pair
    - c. a Higgs boson by hunting for 2 lepton-pairs ( $e^+e^-e^+e^-$ ,  $e^+e^- \mu^+\mu^-$ ,  $\mu^+\mu^-\mu^+\mu^-$ )
  2. If you cannot find such particle pairs, the event might be a background event. Use the pointing tools and particle information in HYPATIA to make your decision. To help you keep track of which events you have looked at, fill in the tally sheet.
  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 a 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 photon – converted photon.
4. If you believe the collision resulted in a background event (no pair of leptons with opposite electric charges and no pairs of photons), ignore the event and proceed to the next one.
  5. After analyzing 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 <http://cernmasterclass.uio.no/OPloT/index.php>, and upload the invariant mass file you have just made.

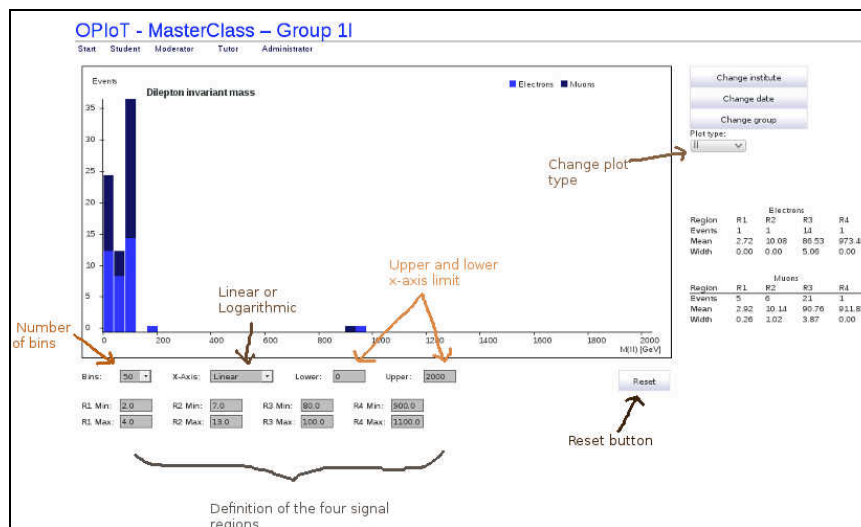
## 10. Gaining and presentation of results

- Student proceed with the uploading of the invariant mass table “Invariant\_Masses.txt” here <http://cernmasterclass.uio.no/OPloT/index.php> following the steps (see also screen shot below):
  1. Students select “Student” menu-item
  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 "1" 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.
  - Can you point out differences/similarities?
  - How often does the Z boson decay into electron-positron pairs? How often does the decay result in muon-antimuon pairs?
  - What did you expect? Why?
  - Do you notice any other particles? At which invariant masses?
- What is the most probable mass of the Z boson?
  - Why is there not one exact value for the Z boson mass?
  - What could be the possible explanations of why the distribution is so wide?
- Have you discovered the Z' boson?
  - If you think so, what is the Z' boson's 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,  $H \rightarrow \gamma\gamma$ ?
  - If not, what could be the reasons?
  - In fact the full sample does contain some real Higgs candidates, even if you have not found them!
- **- 4-lepton measurement**
- Do you see any sign of Higgs decaying to 4 leptons,  $H \rightarrow ZZ \rightarrow llll$ ?
  - If not, what could be the reasons?
  - In fact the whole sample contains one Higgs candidate. At which mass?

## 12. For tutors and moderators: Details on combination and discussion

### For tutors

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:
  - <http://cernmasterclass.uio.no/OPloT/index.php>
  - Username ippog
  - Password mc12
- 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
- Use pdf link "Official ATLAS results"

See screen shots of section 10.

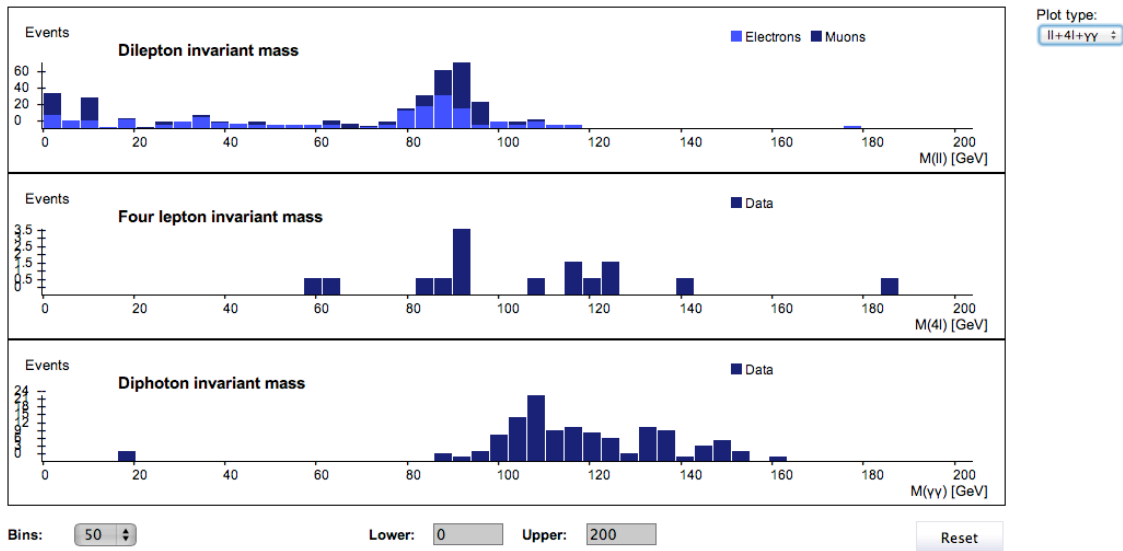
### For moderators

- Go to the plot-submission page:
  - <http://cernmasterclass.uio.no/OPloT/index.php>
  - Username ippog
  - Password mc12
- Click on the "Moderator" menu-item
- Choose the right year-month-day in the three drop-down menus
- Click on "Combination plot - all institutes" for the total combination of all the institutes participating that day
- A set of plots will appear, which is the combination of all groups' results
- Use pdf link for "Official ATLAS results"

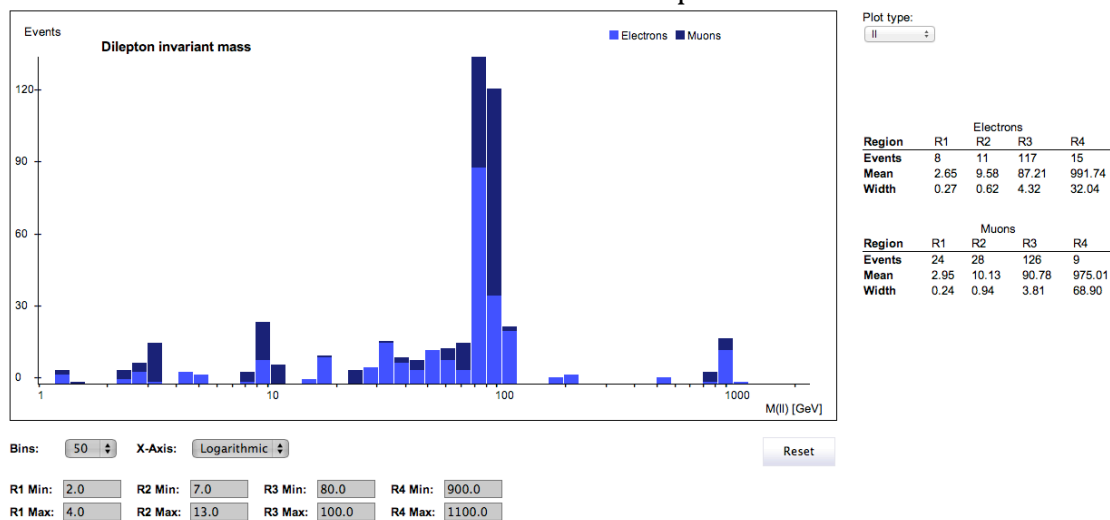
The screen shots of section 10 remind how to proceed with OPloT.

In the following, some examples of combined plots obtained with a small sample of events are commented.

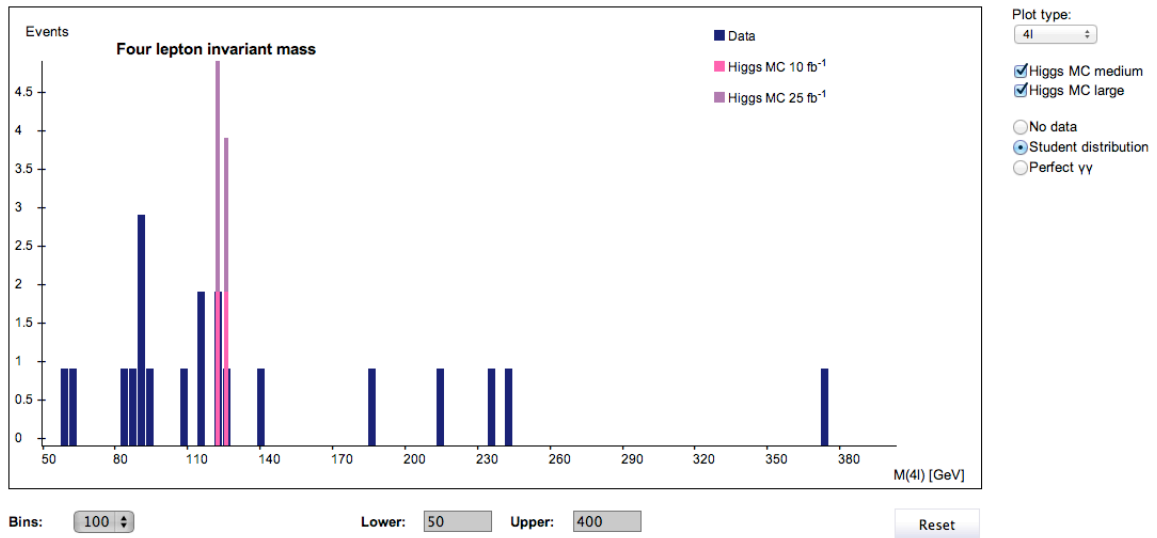
The figure below shows the 3 invariant mass distributions (" $ll+4l+\gamma\gamma$ " chosen as "Plot type"). Number of bins and lower/upper values of x-axis can be changed.



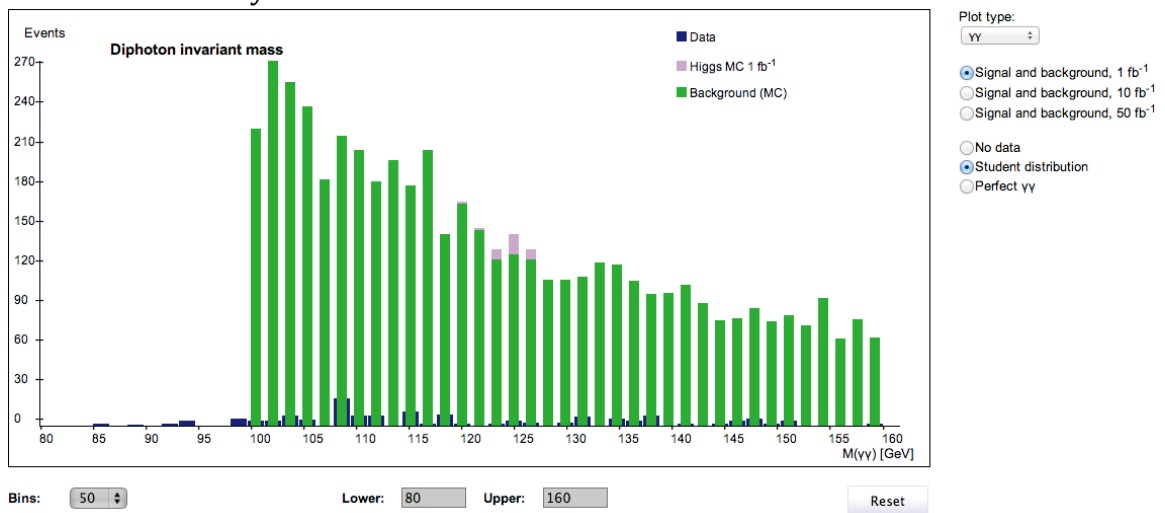
Below only the “ll” type is chosen. Note that logarithm scale is used for the x-axis in order to clearly see 4 resonances simultaneously:  $J/\psi$  ( $\sim 3$  GeV),  $Y$  ( $\sim 10$  GeV),  $Z$  ( $\sim 90$  GeV), and  $Z'$  ( $\sim 1000$  GeV). The table to the right summarises the results (mass and width) of the 4 particles corresponding to the 4 regions R1-4. Final states with electrons and with muons can be compared.



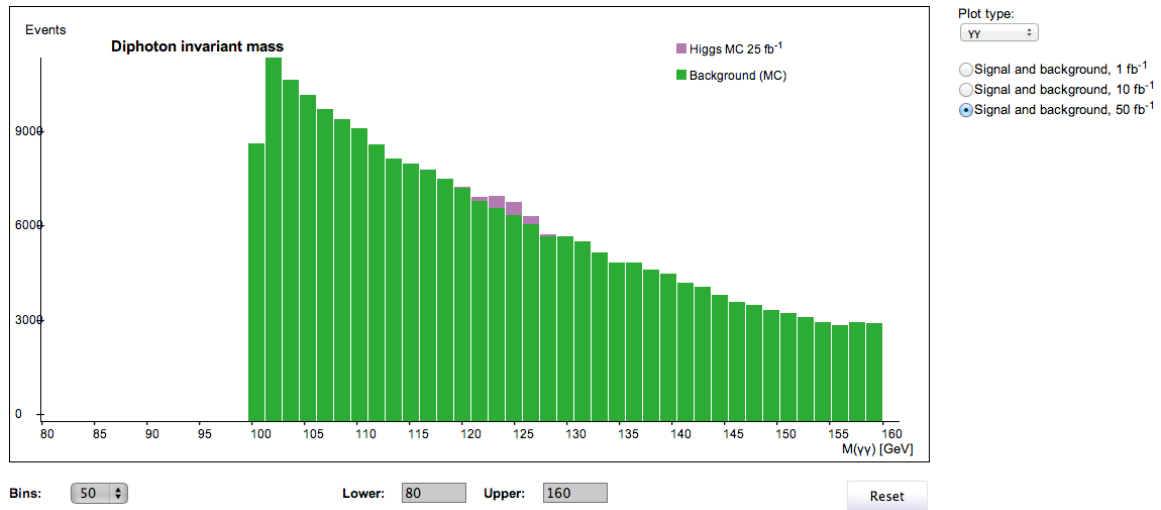
The invariant mass of 4 leptons is shown below – plot type “4l” chosen. In addition to the “student distribution”, two coloured “Higg MC” distributions are added for two luminosities (medium  $10\text{fb}^{-1}$  and large  $25\text{fb}^{-1}$ ), showing how many Higgs events are expected assuming the 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.



The invariant mass of 2 photons is given below – plot type “ $\gamma\gamma$ ” chosen. Data obtained by the students are in blue. The expected simulated background (green) and 125 GeV Higgs signal (pink) (“Signal and background 1fb<sup>-1</sup>” ticked). Note that if all  $\gamma\gamma$  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<sup>-1</sup> of data are not enough to disentangle the signal from the background. More data are enough to “claim discovery”.



To claim discovery, ATLAS analysed more than 10fb<sup>-1</sup> of data. The next figure demonstrates that with 25fb<sup>-1</sup> a clear signal singles out on top of a smooth exponential background.



### 13. Supporting material for students

- Cheat-sheet to
  - 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 (talks, films, animations, documentations...)

- A couple of slides for the institute / moderator discussions
- Some detailed examples of event categorisation
- More on decays of Z and Higgs
- Introductory lectures I and II
  - In Norwegian
  - In English?