The Z path measurement – introduction for moderators

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Moderators' orientation
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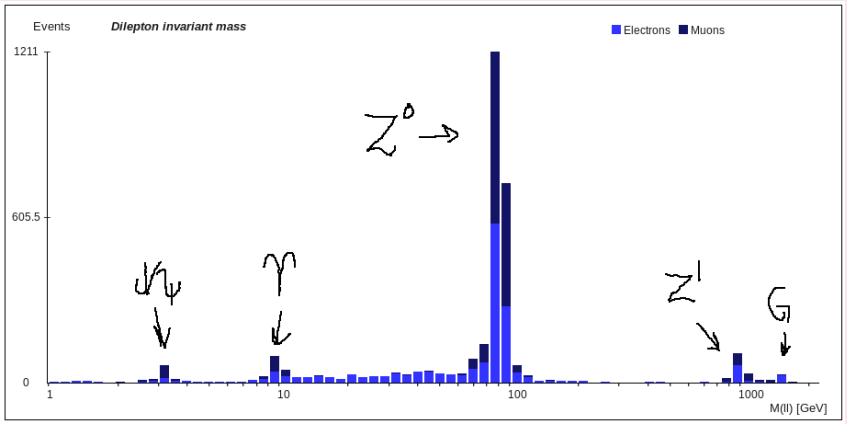
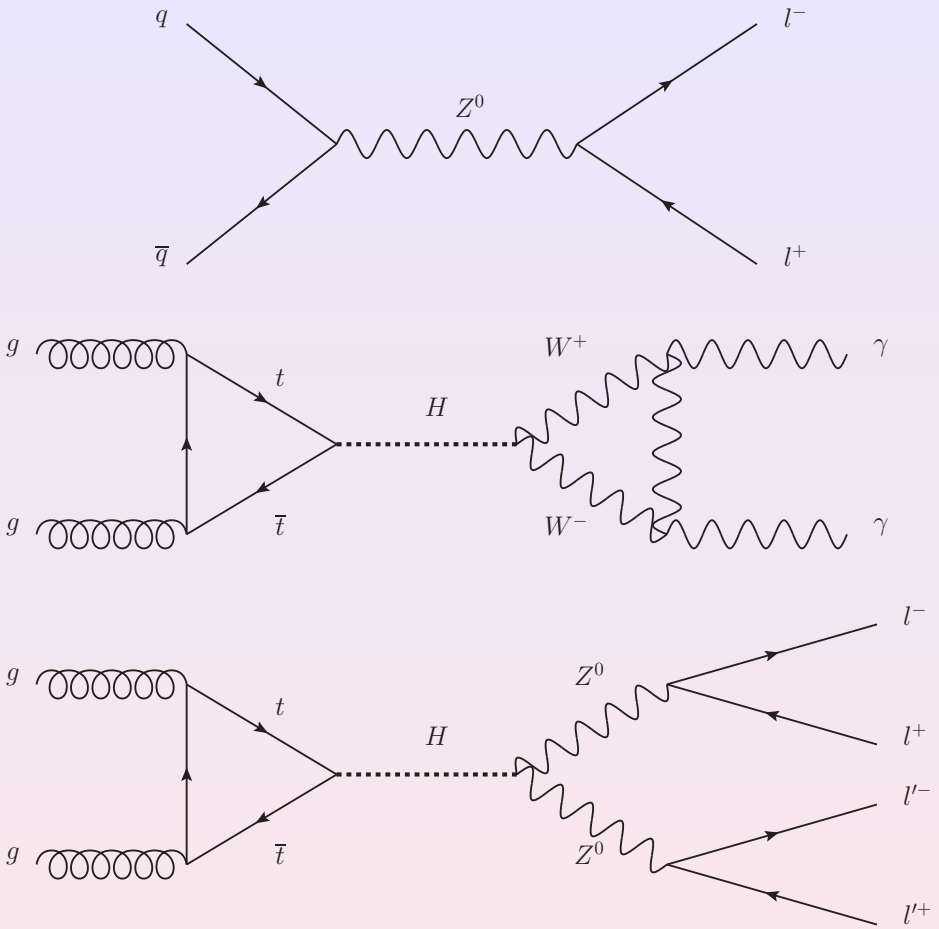
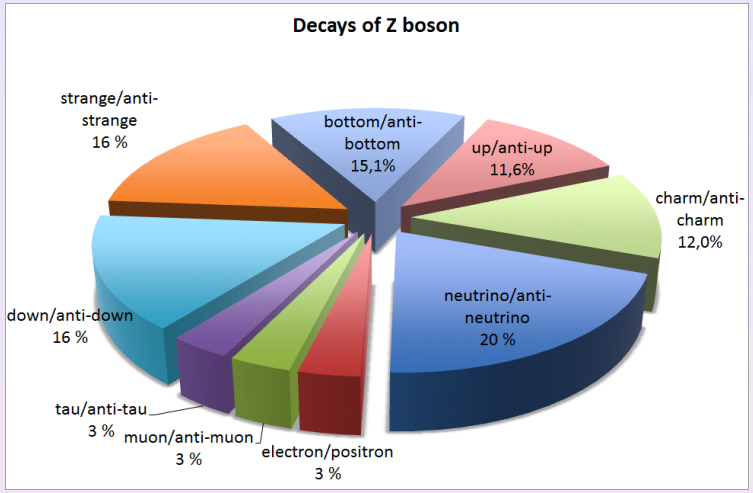
Overview and goals

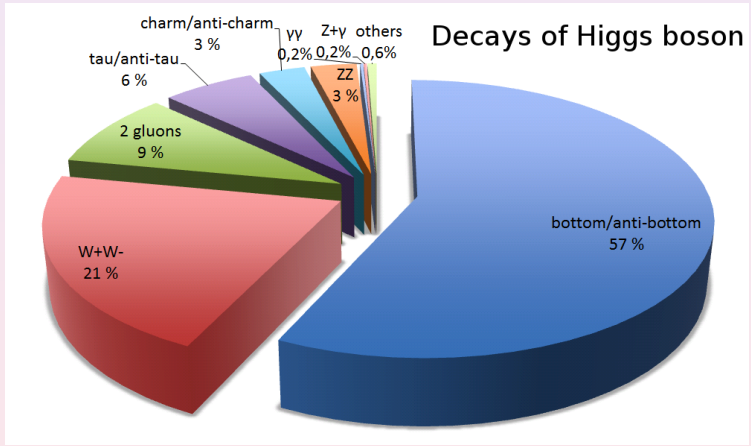
- The students go through events using event displays
  - Looking for good electron, muon, and photon candidates
  - Identifying events with dileptons ($e^+e^-/\mu^+\mu^-$), diphotons ($\gamma\gamma$), or 4 leptons ($e^+e^-e^+e^-$, $e^+e^-\mu^+\mu^-$, $\mu^+\mu^-\mu^+\mu^-$)
  - Calculating invariant masses and uploading these in the end to a plotting tool
- In the end, results are combined, and invariant mass distributions are built, where the students may have
  - Identified and measured masses(/widths) of well-known particles such as the J/ψ, Υ, and Z^0
  - Identified good Higgs-boson candidates
  - Discovered new particles (Z', Graviton)



Physics background

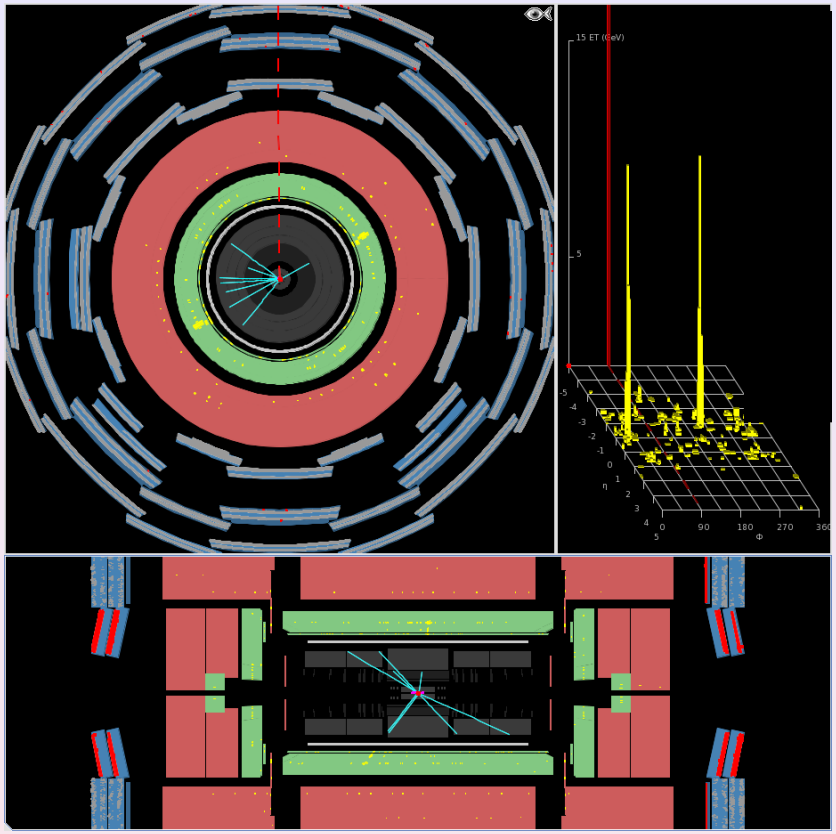


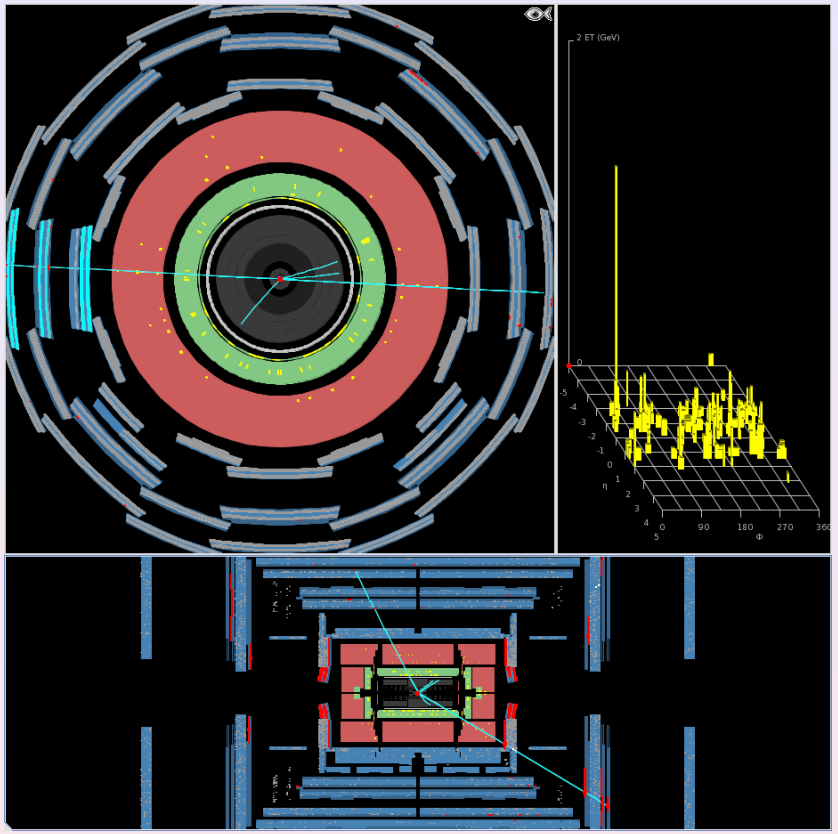




- Looking for rare decays (especially for Higgs) which are easily distinguishable from background

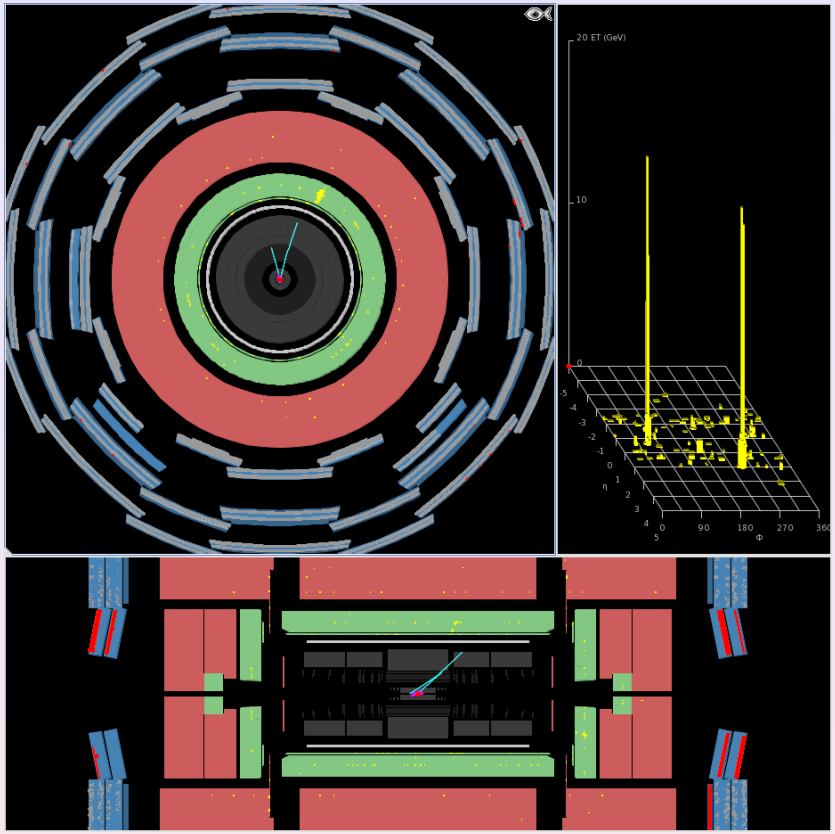
Identifying events in HYPATIA

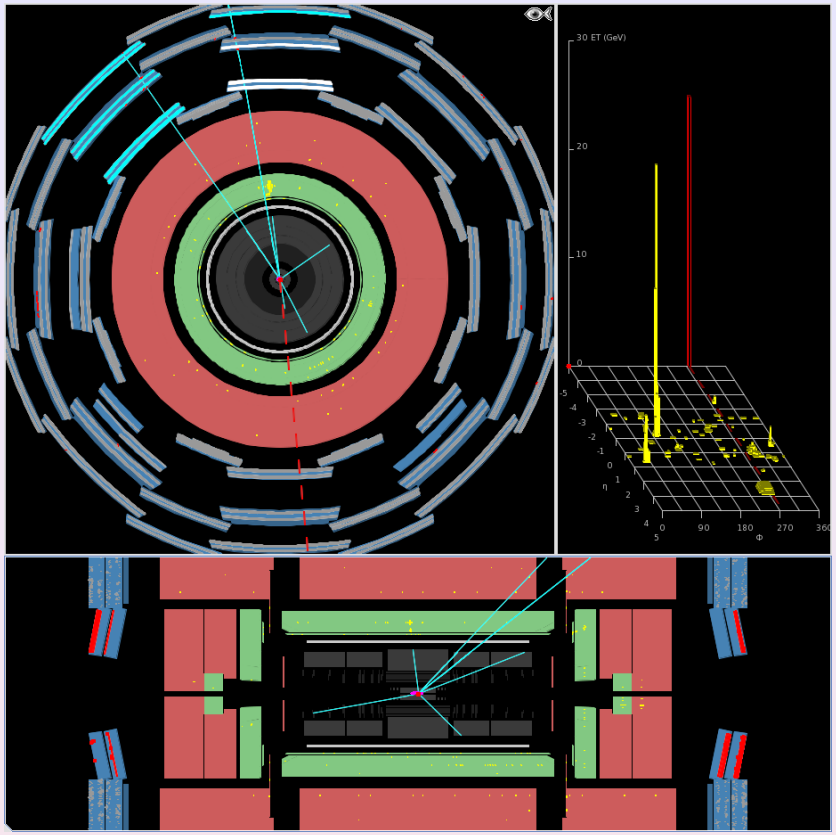




- Electron: concentrated energy deposit in EM calorimeter and associated track
- Muon: long track through whole detector

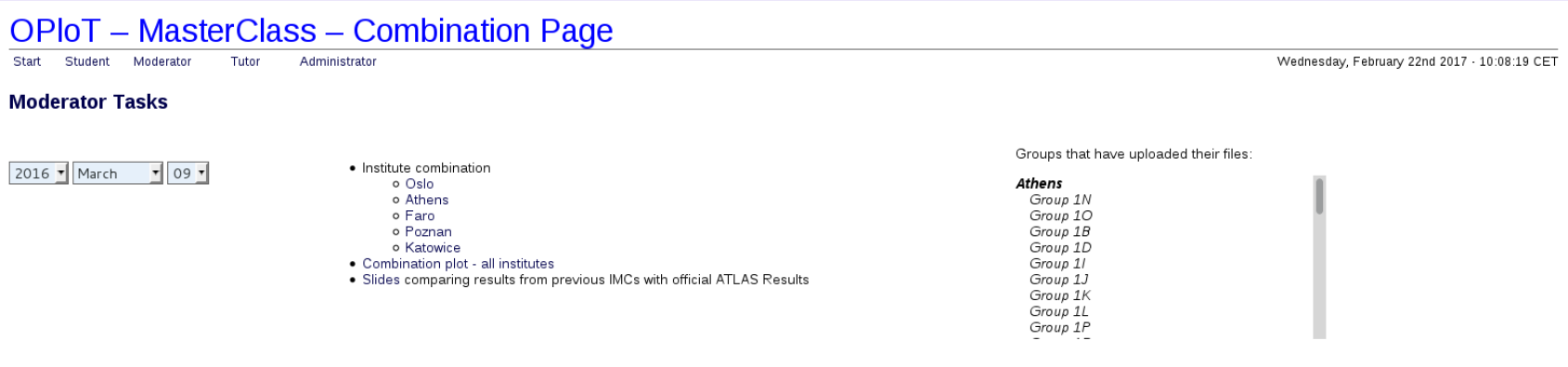
Identifying events in HYPATIA





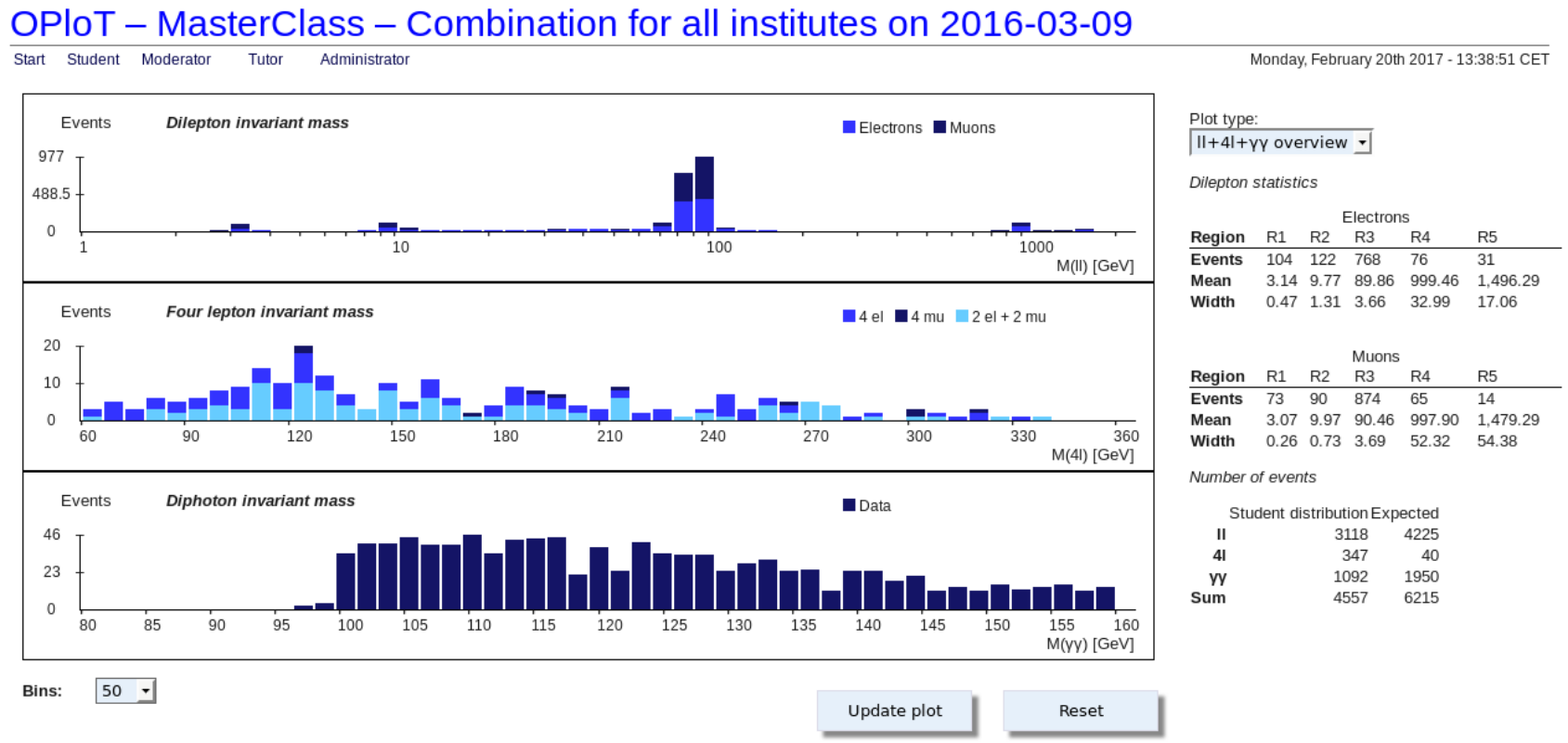
- Photon: electron-like EM energy deposit, but no track (unless converted)
- In all cases, students select objects which they identify as electron, muon, or photon, and HYPATIA calculates the corresponding invariant mass

The online plotting tool (OPloT)



- Click “Moderator” (no password required)
- Select date
- You can see which groups have uploaded their results
- Click “Combination plot – all institutes” to see combined results for all uploaded data on the given date

Z path results from 2016



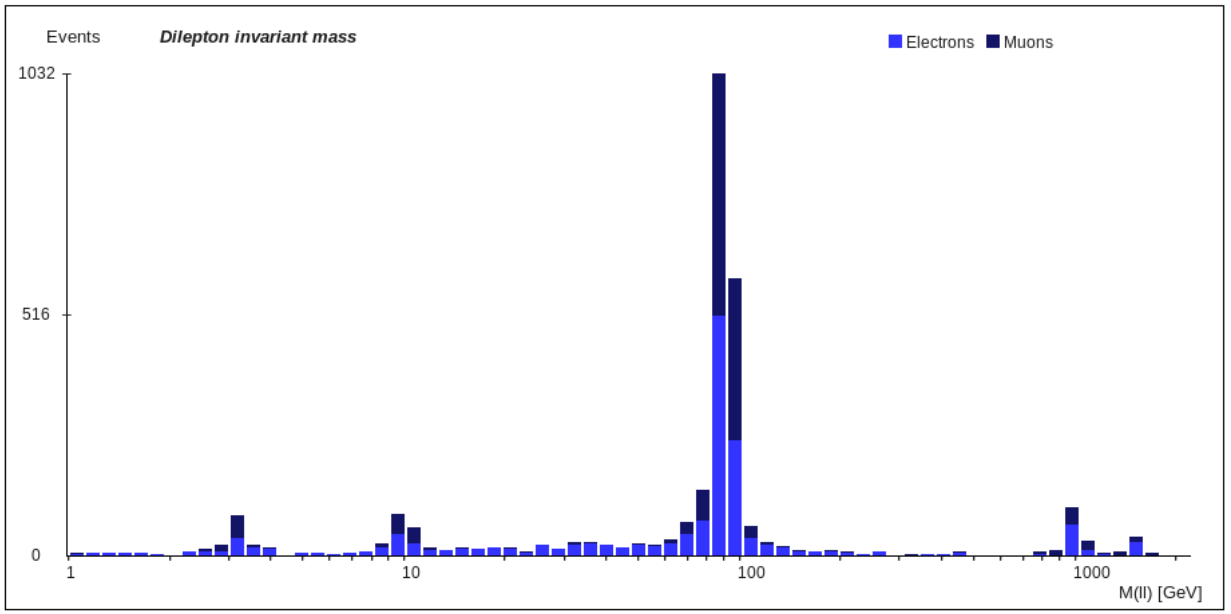
- "All institutes combination" start page
- Invariant mass distributions for all final states
- Table with estimated masses and widths
- Table with event counts compared to expectations

Z path results from 2016

OPloT – MasterClass – Combination for all institutes on 2016-03-09

Start Student Moderator Tutor Administrator

Monday, February 20th 2017 - 13:42:20 CET



Plot type: ll

Dilepton statistics

	Electrons				
Region	R1	R2	R3	R4	R5
Events	104	122	768	76	31
Mean	3.14	9.77	89.86	999.46	1,496.29
Width	0.47	1.31	3.66	32.99	17.06

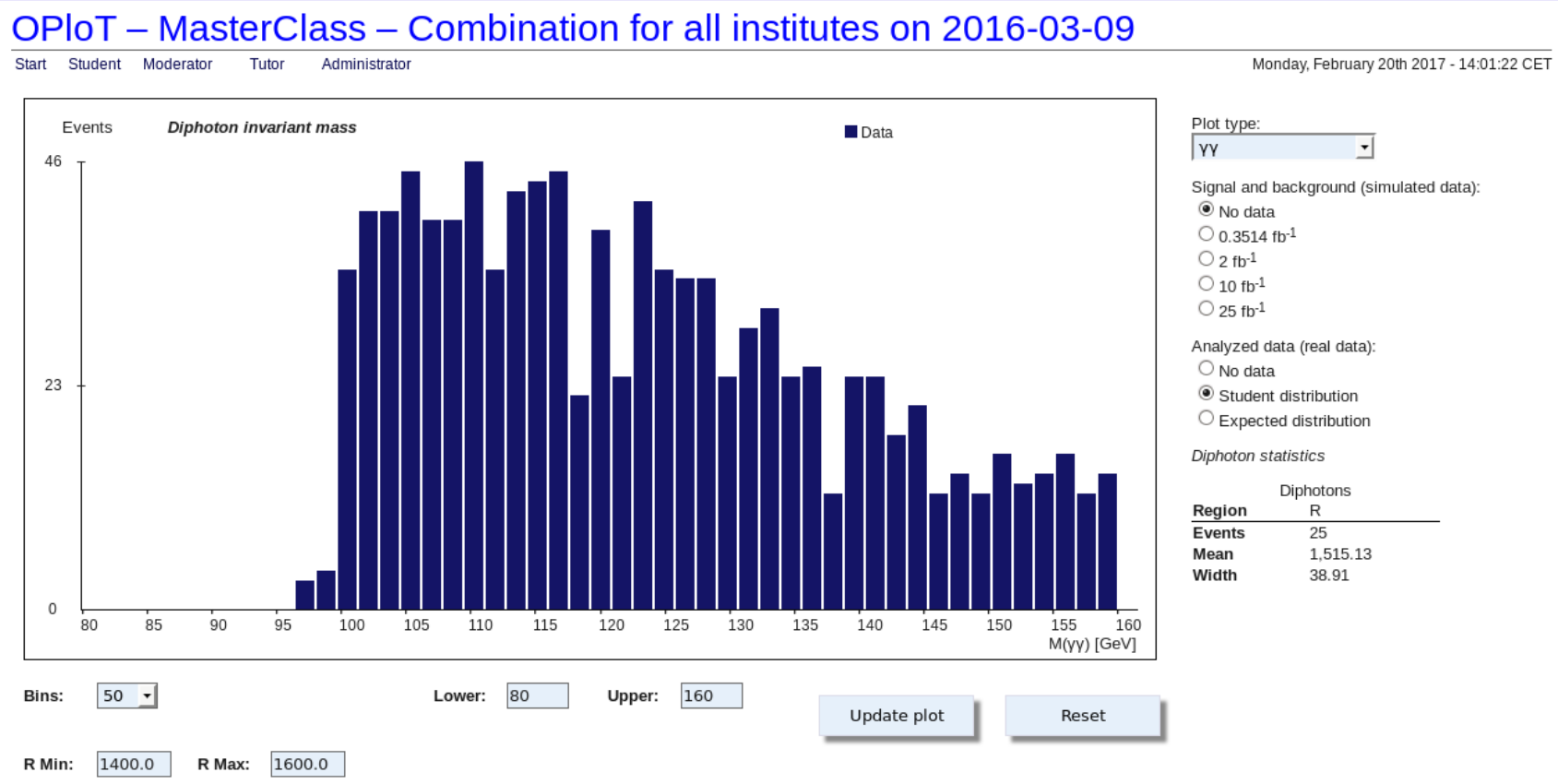
	Muons				
Region	R1	R2	R3	R4	R5
Events	73	90	874	65	14
Mean	3.07	9.97	90.46	997.90	1,479.29
Width	0.26	0.73	3.69	52.32	54.38

Bins: 70 **X-Axis:** Logarithmic **Upper:** 2000 Update plot Reset

R1 Min:	2.0	**R2 Min:**	7.0	**R3 Min:**	80.0	**R4 Min:**	900.0	**R5 Min:**	1400.0
R1 Max:	4.0	**R2 Max:**	13.0	**R3 Max:**	100.0	**R4 Max:**	1100.0	**R5 Max:**	1600.0

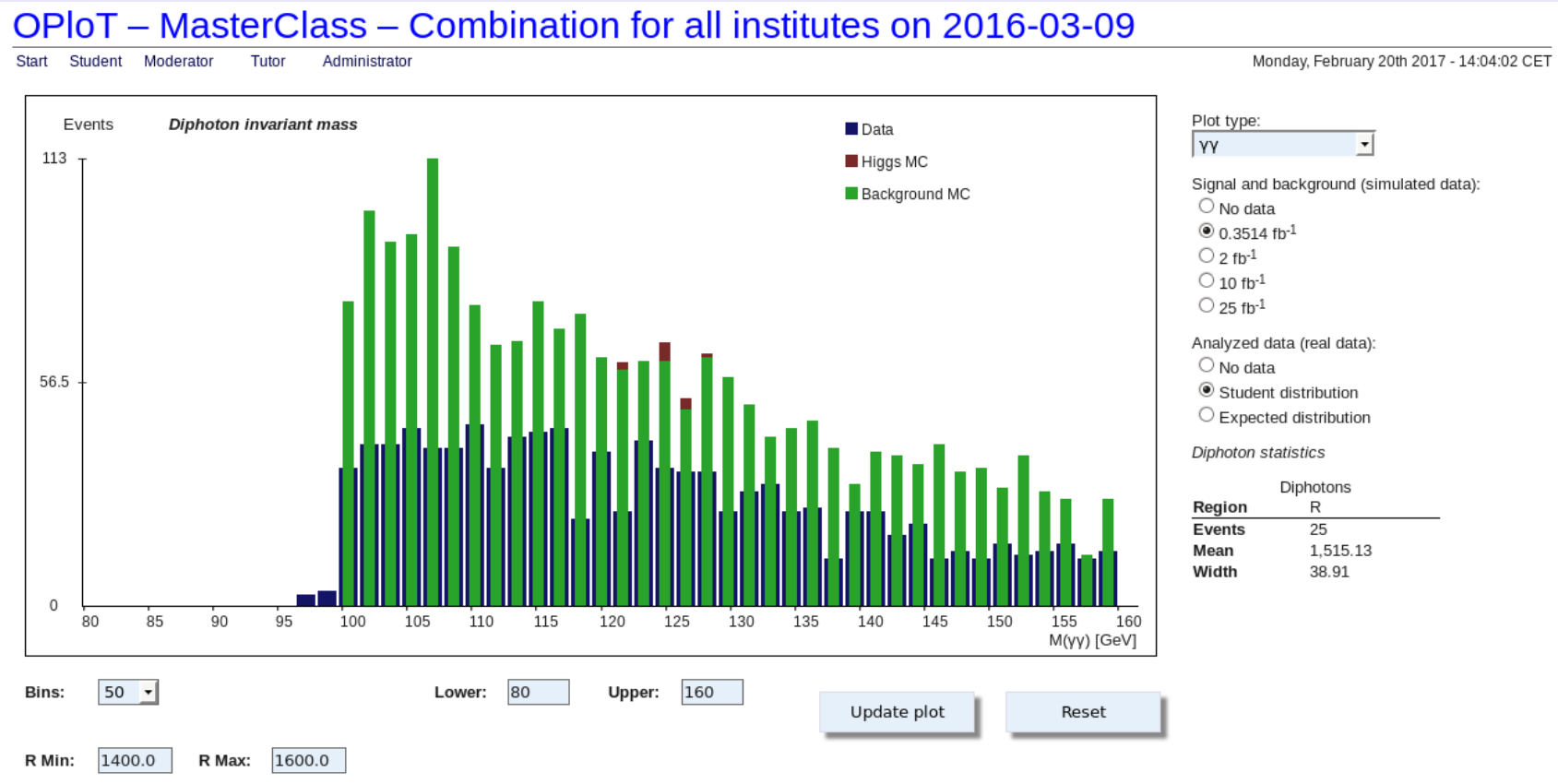
- Dilepton invariant mass distribution
- Can identify J/ψ, Υ, Z^0, Z', and graviton
- The latter two come as a surprise to the students (most likely already covered in the institute level review)

Z path results from 2016



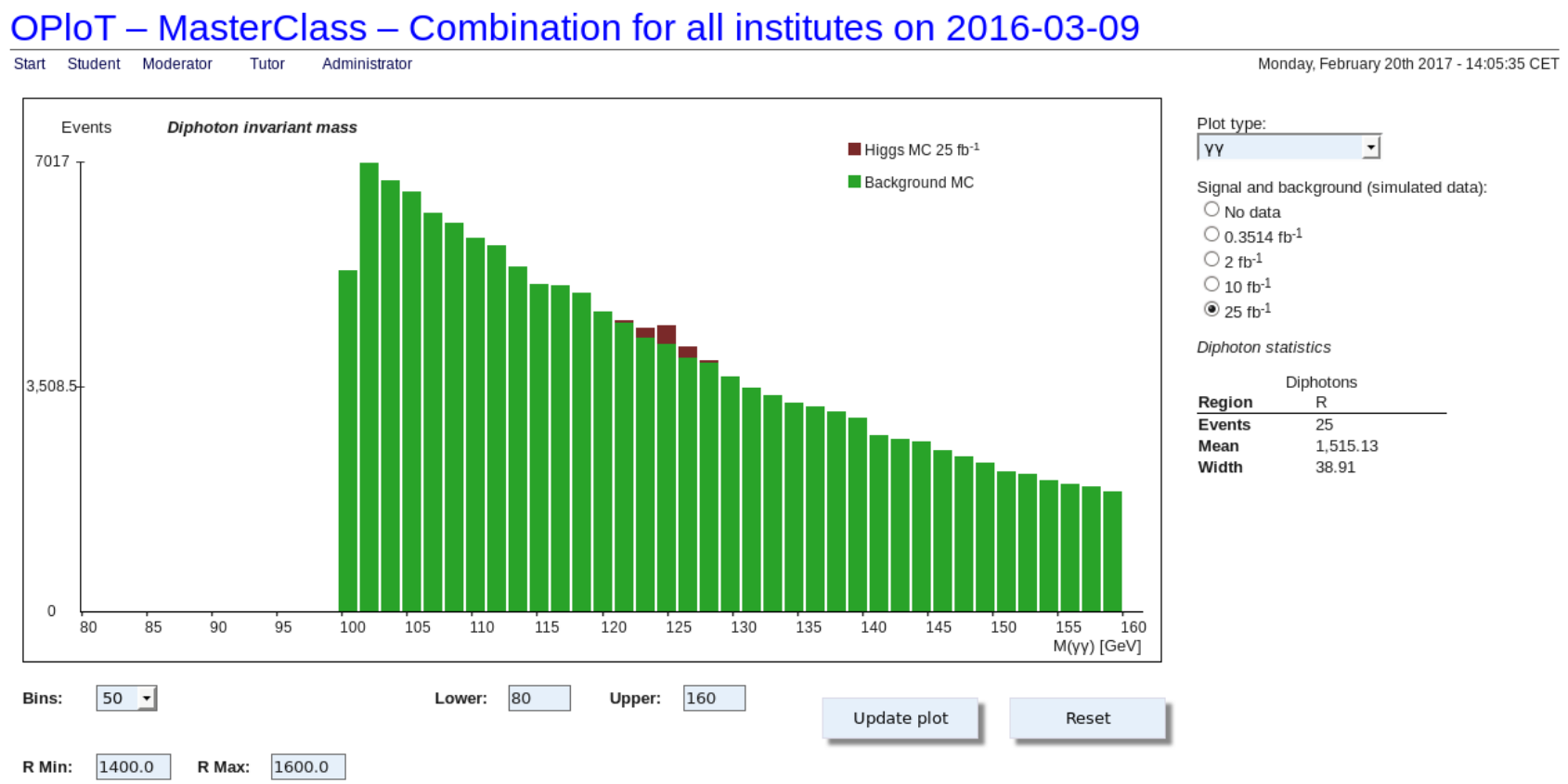
- Diphoton invariant mass distribution
- In principle sensitive to Higgs contribution
- Statistics is too low to make a discovery

Z path results from 2016



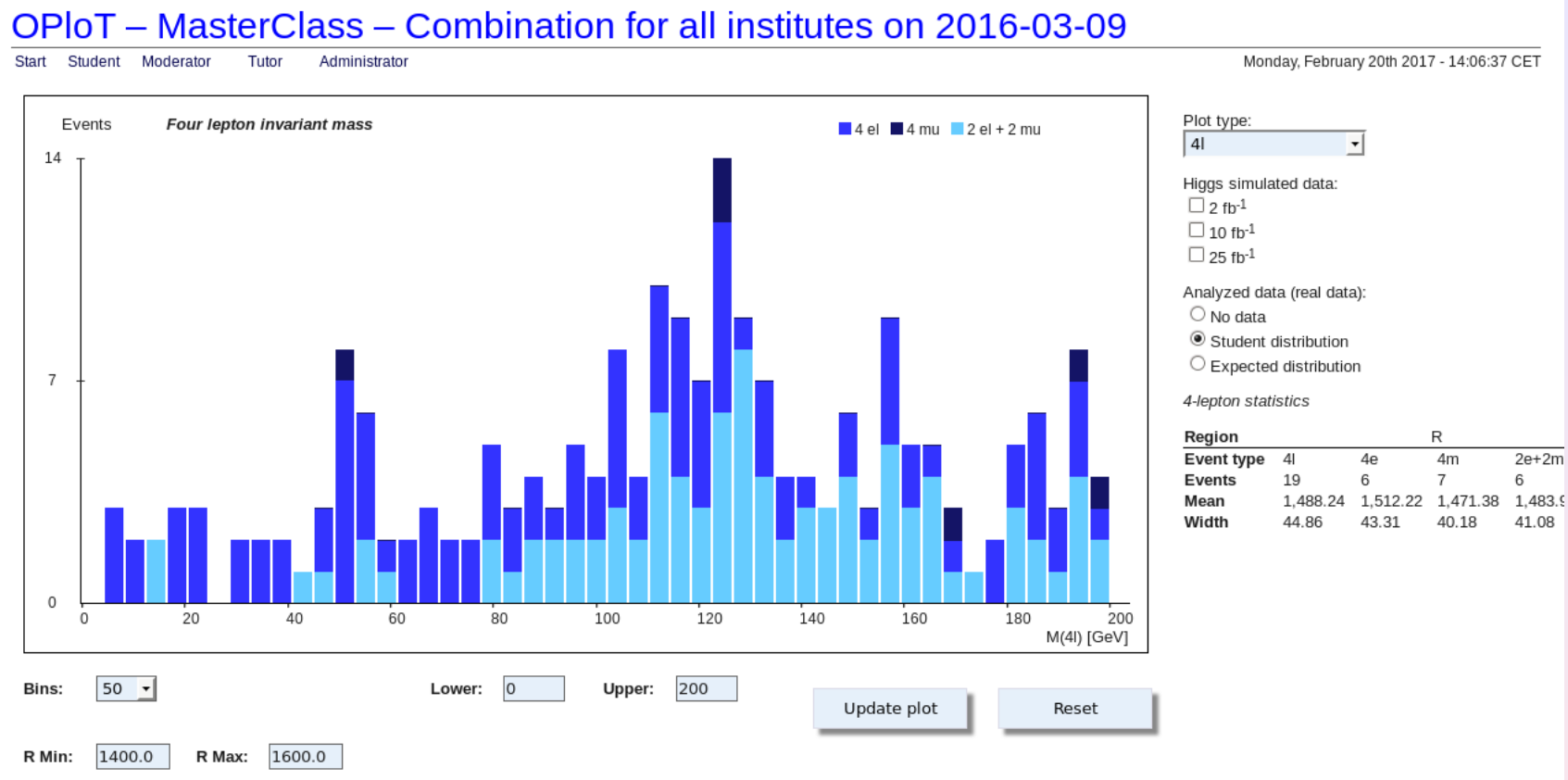
- Compare students' results to simulated background and signal corresponding to the analysed integrated luminosity

Z path results from 2016



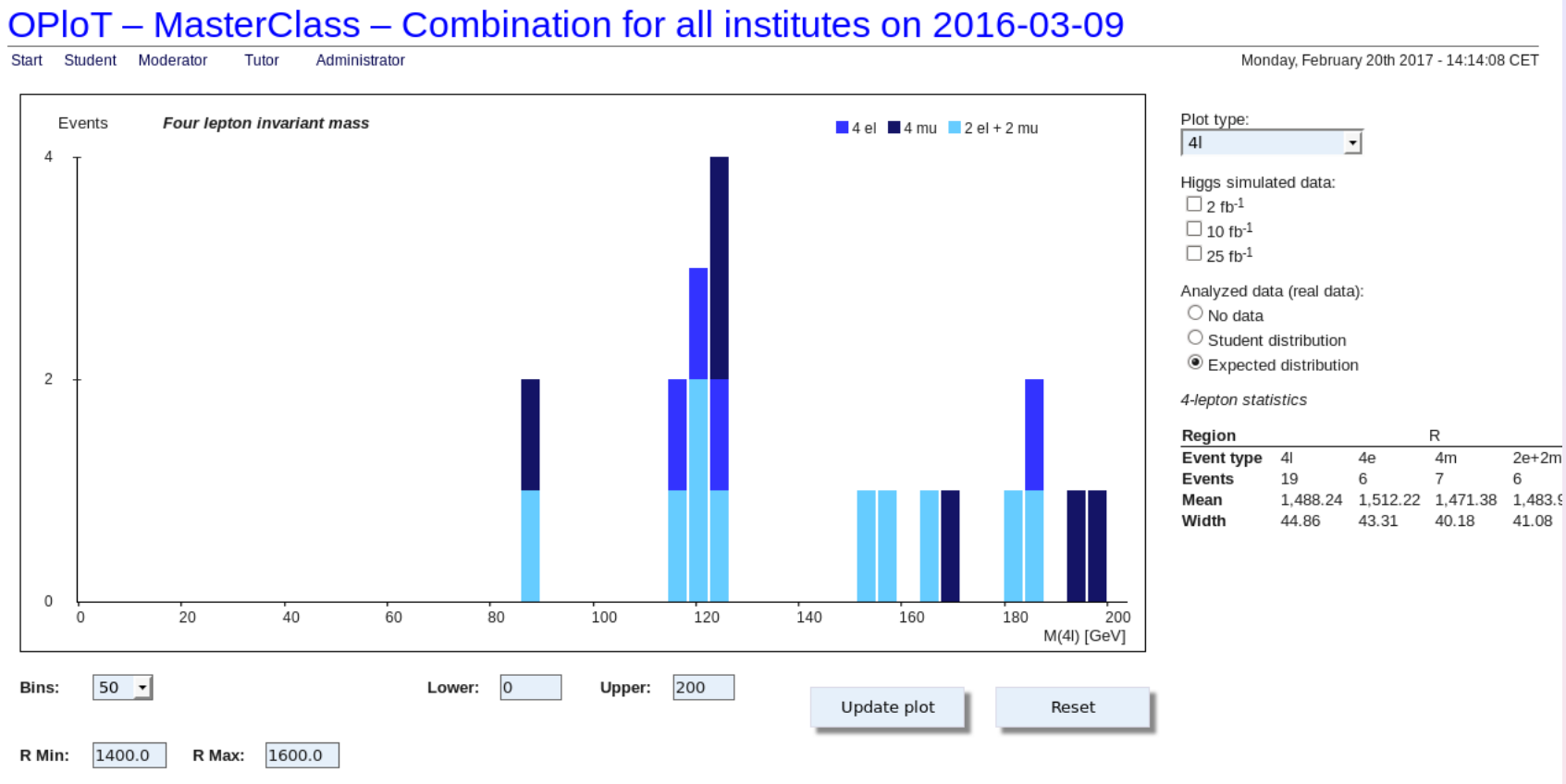
- Look at simulated background and signal for larger amounts of integrated luminosity
- $\Rightarrow$ we could have seen the Higgs, we just need more data...

Z path results from 2016



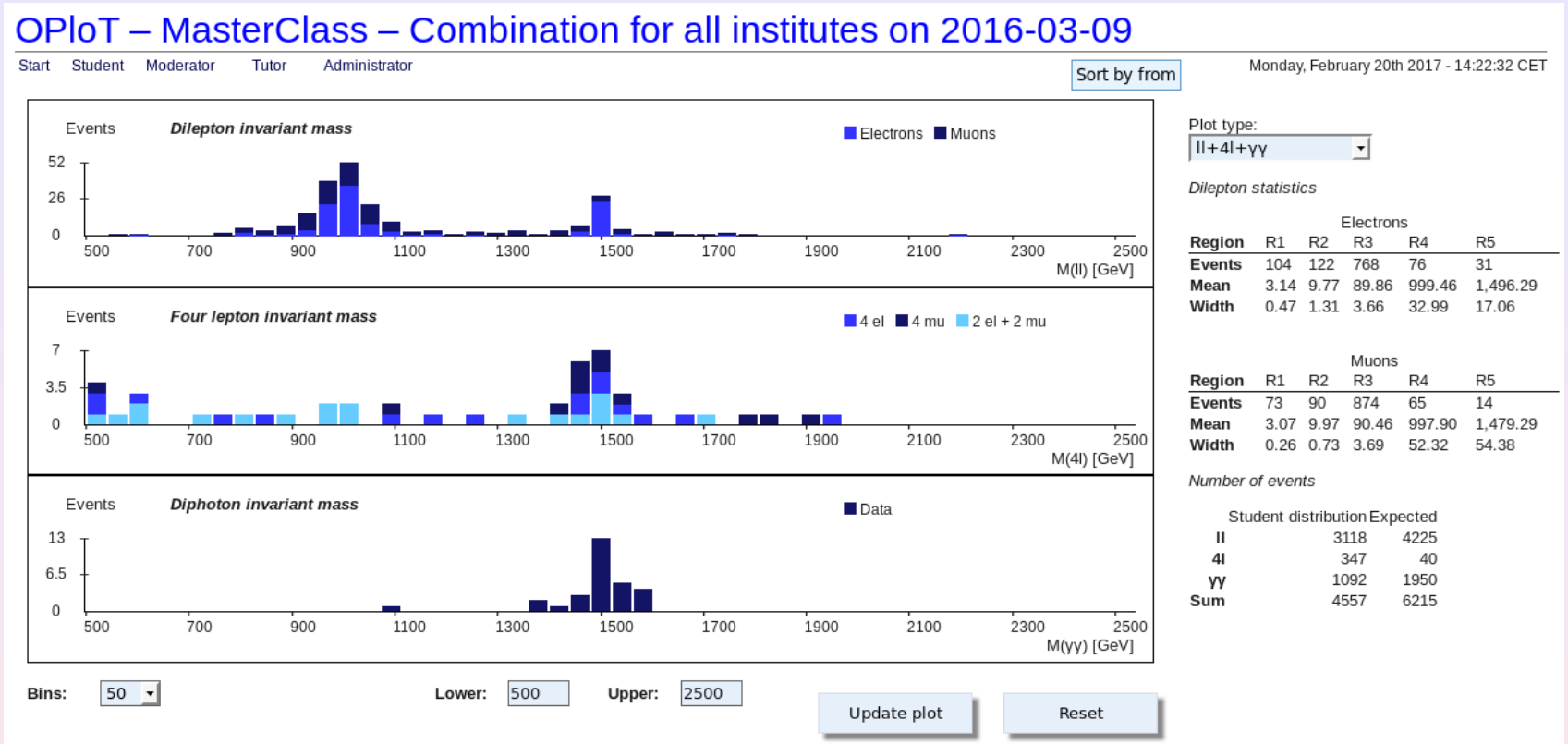
- 4-lepton invariant mass distribution
- Huge number of events (remember table in overview page)
- Notice composition in terms of $4e$, $2e2\mu$, 4μ
- Much easier to find fake electrons

Z path results from 2016



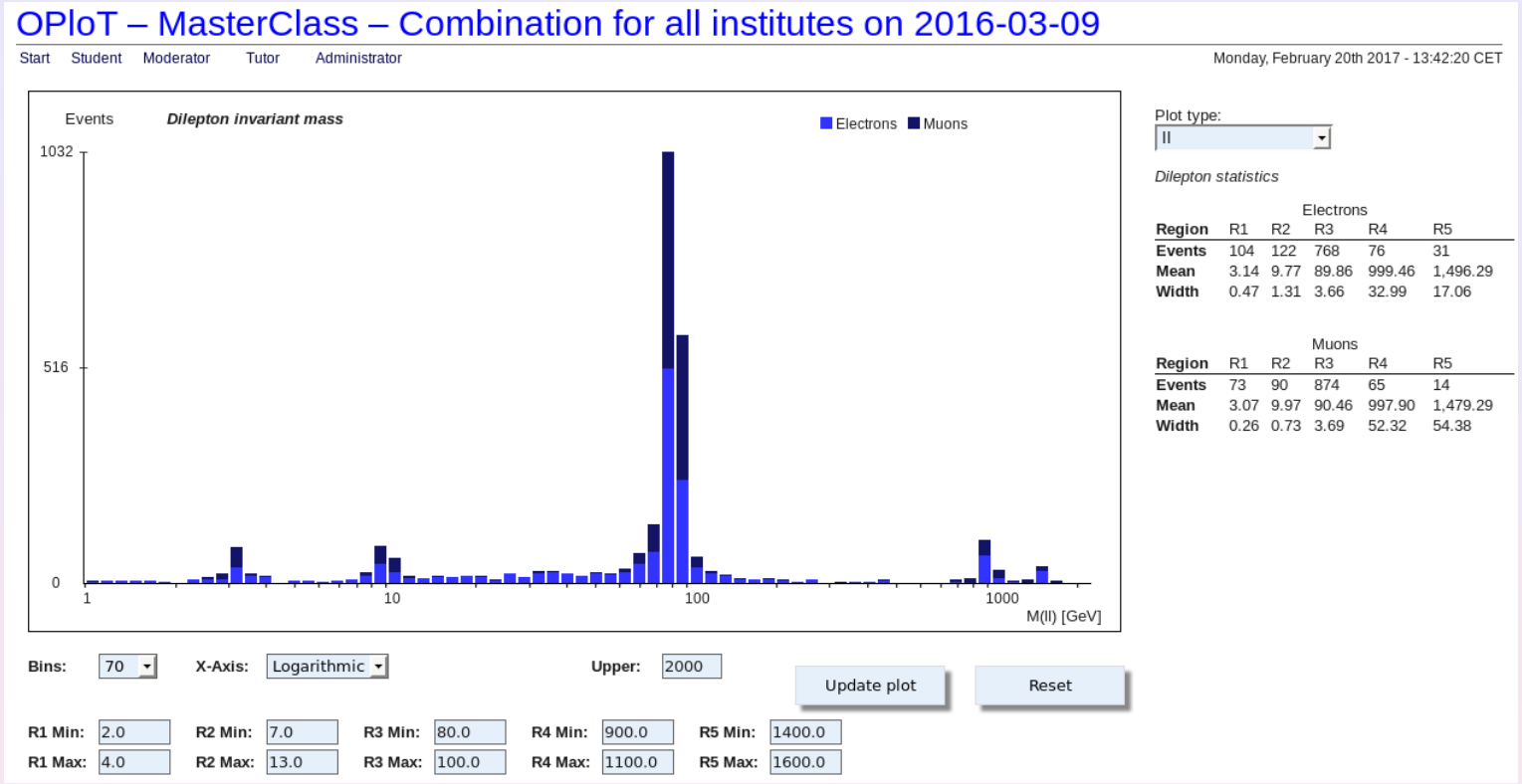
- Expected distribution shows what the students would find with “perfect event identification”
- A few nice Higgs candidates with very little background
- Many participating students looked at these prime candidates during the day!

Z path results from 2016



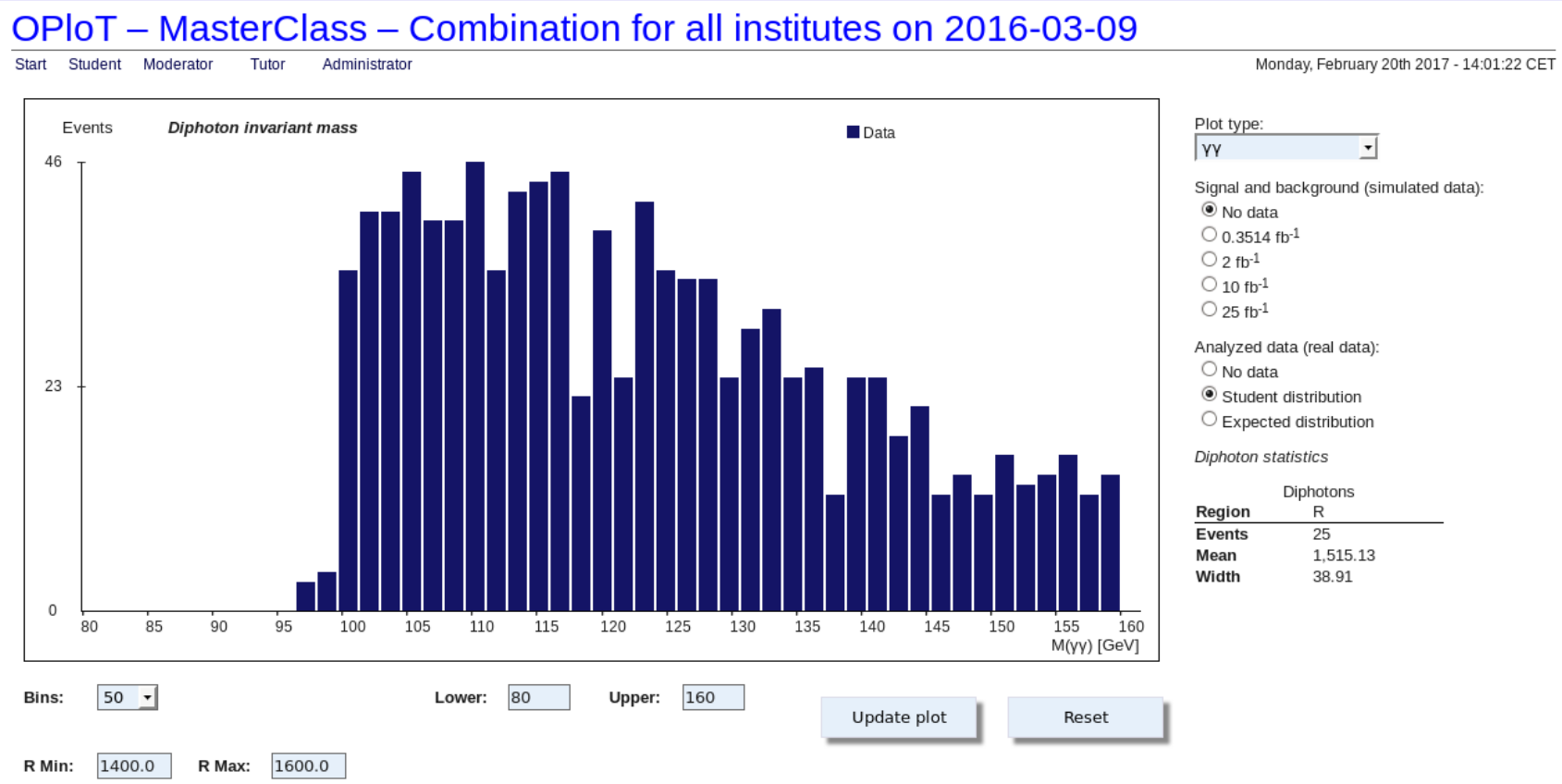
- Investigate high mass range in all final states simultaneously
- Z' seen only in dilepton distribution
- Graviton shows up in all of them!
- A manifestation of spin

Moderator “scenarios” (see here)



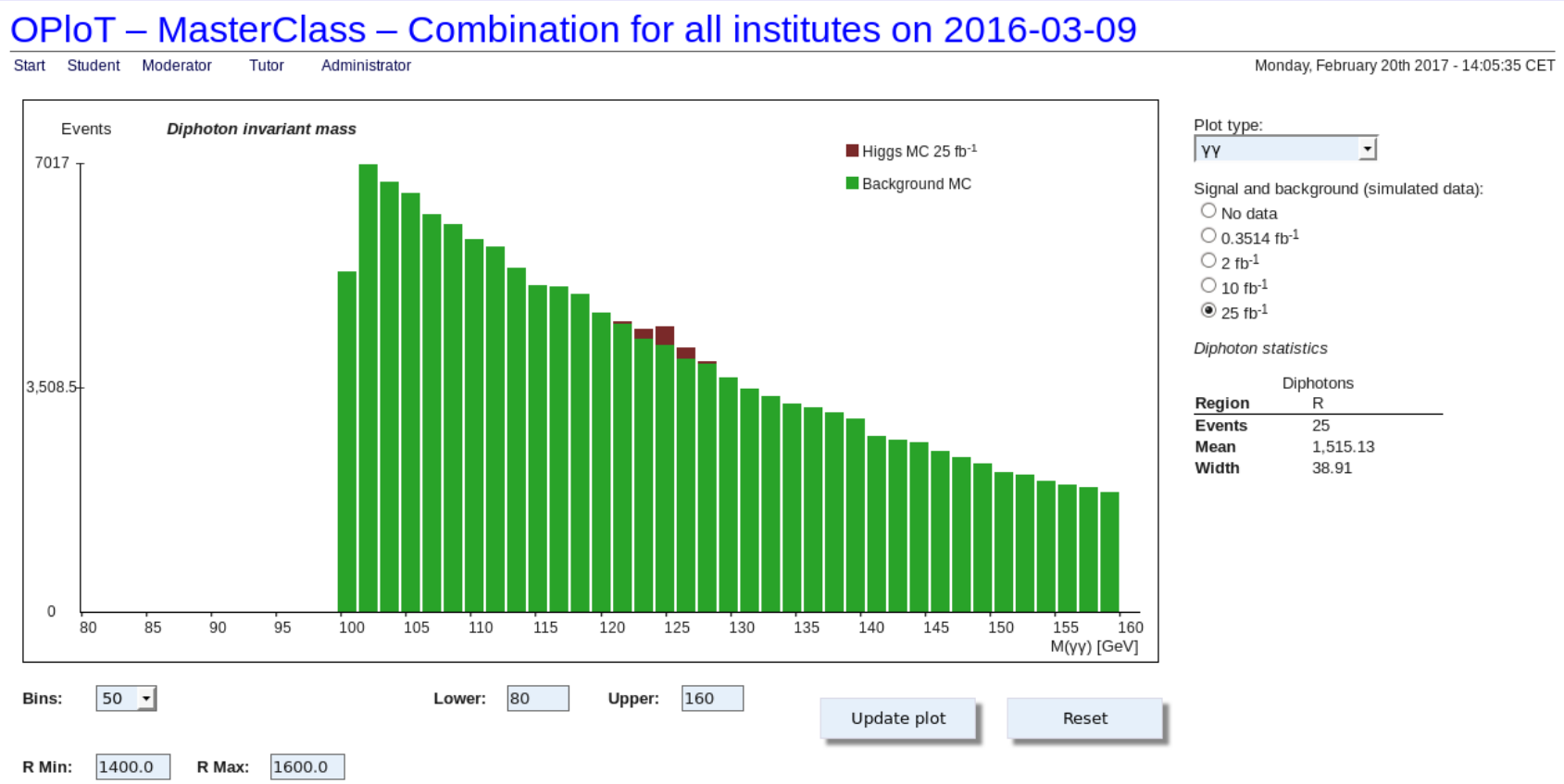
- Explain what a peak is, point out Z boson peak at 90 GeV
- **Poll question:** Do you see any peaks here that you would not expect?
- Discuss J/ψ and Υ, and explain that we “injected” Z' and graviton events at 1 TeV and 1.5 TeV

Moderator “scenarios” (see here)



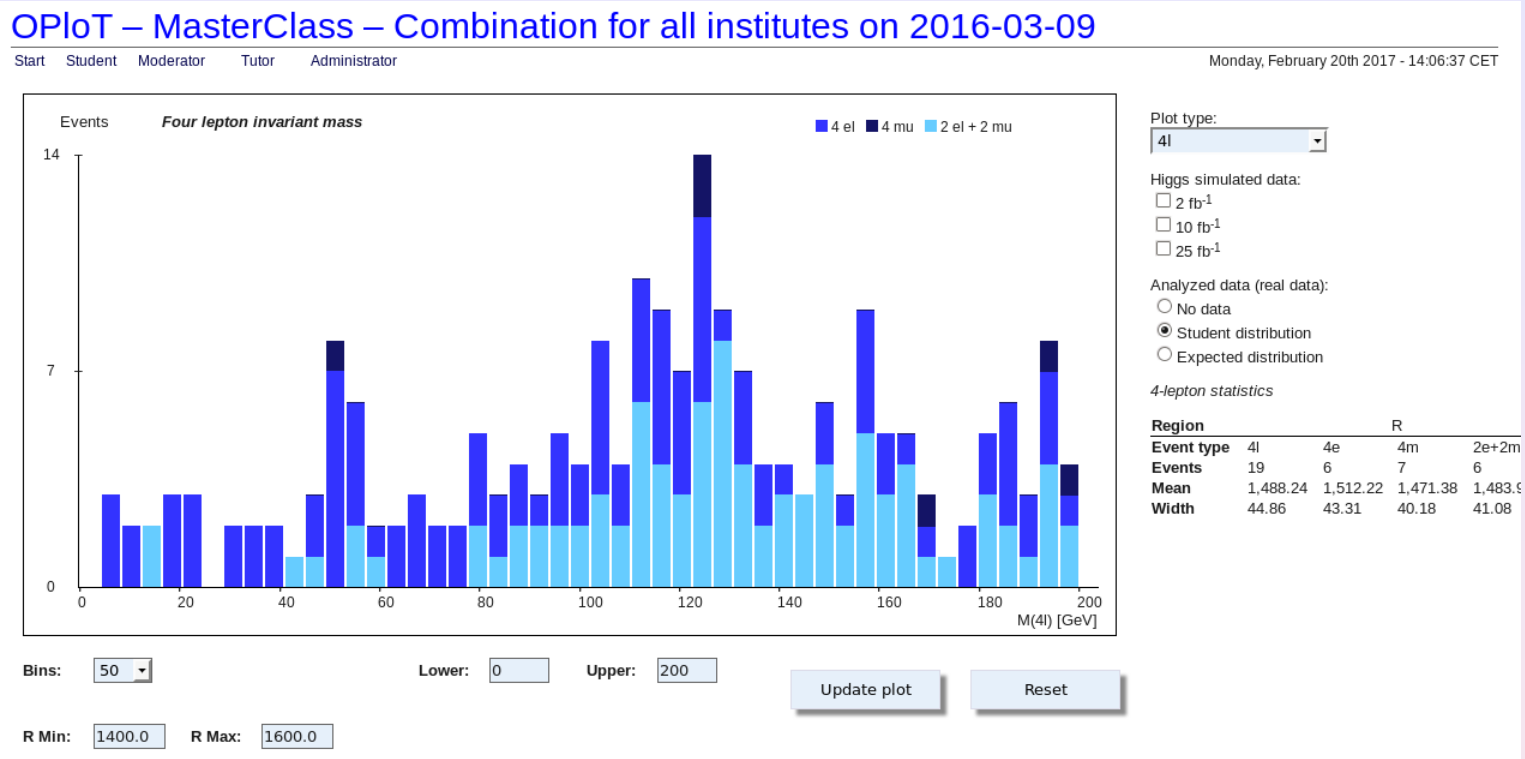
- **Poll question:** Do you see a peak corresponding to the Higgs boson?
- Explain about statistical limitations of the measurements and that $H \to \gamma\gamma$ is a very rare process

Moderator “scenarios” (see here)



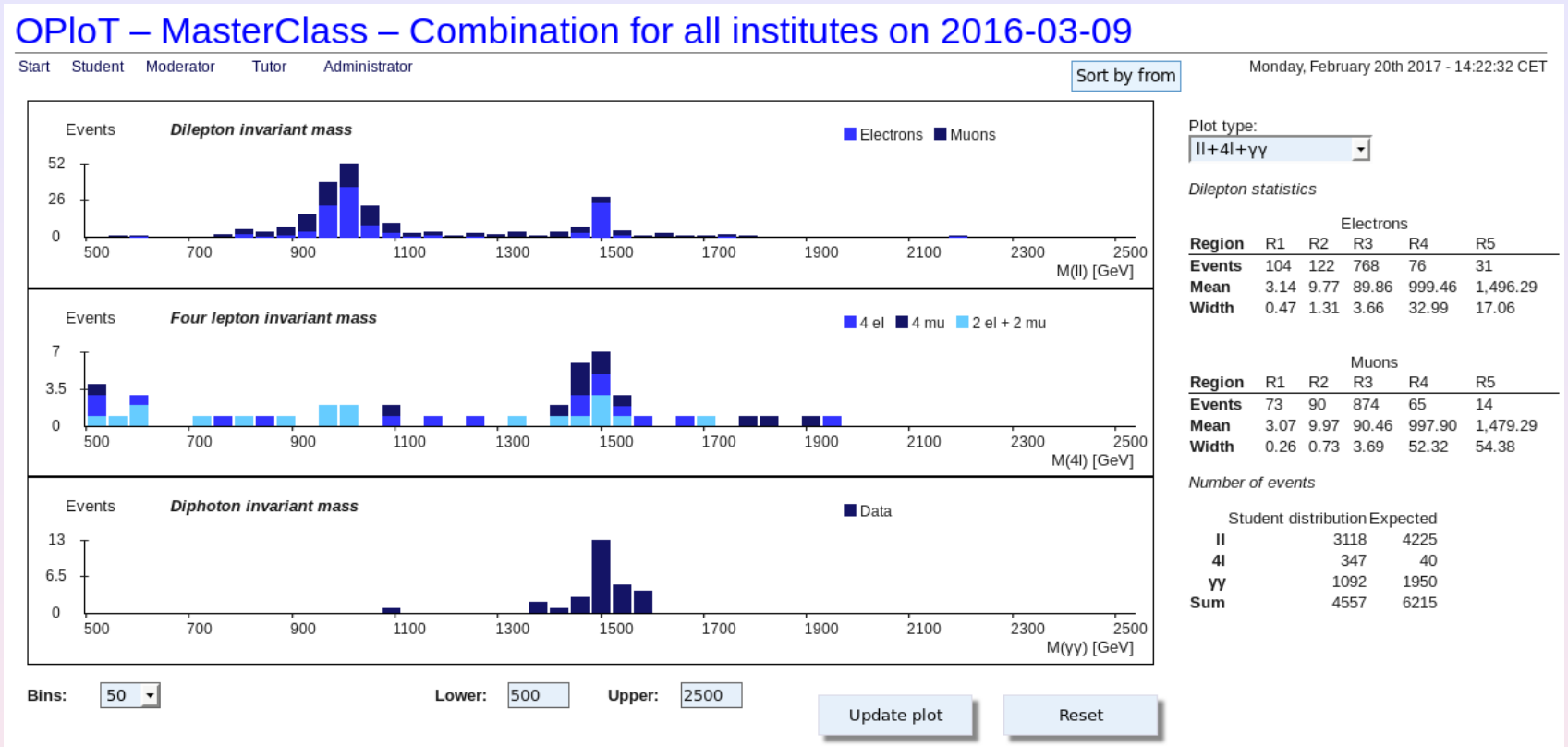
- Explain that you’re now showing the results scaled up to a much larger amount of data
- **Poll question:** Do you think we could see the peak here even if it had the same color as the background?

Moderator “scenarios” (see here)



- Explain the plot and that we’re now looking for Higgs bosons decaying to two Z bosons (with $Z \to ee$ or $Z \to \mu\mu$)
- **Poll question:** Why are there more events with electrons in than muons?
- Explain that the Z boson decays to e^+e^- and $\mu^+\mu^-$ at equal rates, but electrons are easier to fake

Moderator “scenarios” (see here)



- **Poll question:** Why don’t we see the particle at 1000 GeV in the 4-lepton and diphoton distributions?
- Explain that observing how a particle decays can give us lots of information about its properties, in this case in particular about the spin

Summary

- Students look for dilepton, diphoton, and 4-lepton events to search for
  - $Z^0 \to l^+ l^-$ (and other dilepton resonances)
  - $H \to \gamma\gamma$ (and other diphoton resonances)
  - $H \to l^+ l^- l'^+ l'^-$ (and other 4-lepton resonances)
- Invariant masses are calculated in HYPATIA and uploaded to OPIoT
- Invariant mass distributions are built for the combination of all students' data, showing resonance peaks corresponding to known and new particles
- 5 "scenarios" are provided as suggestions to guide the discussion with the students in the video conference