

The Z path measurement – introduction for moderators

~~Magnar K. Bugge~~

ERIK GRAMSTAD

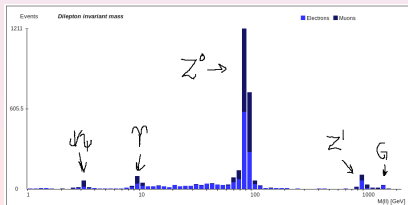
University of Oslo

Moderators' orientation

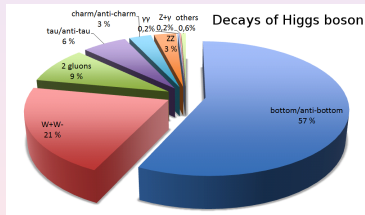
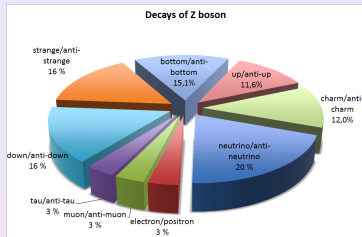
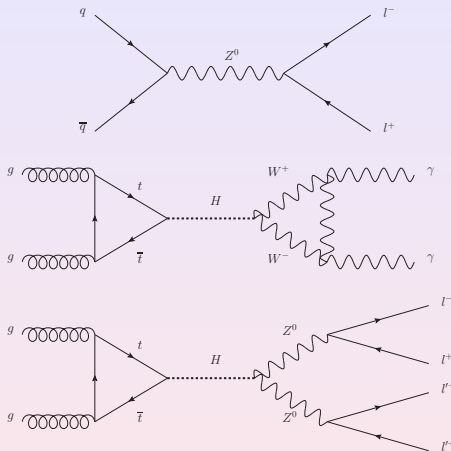
February ~~2021~~ 2024 2025

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)

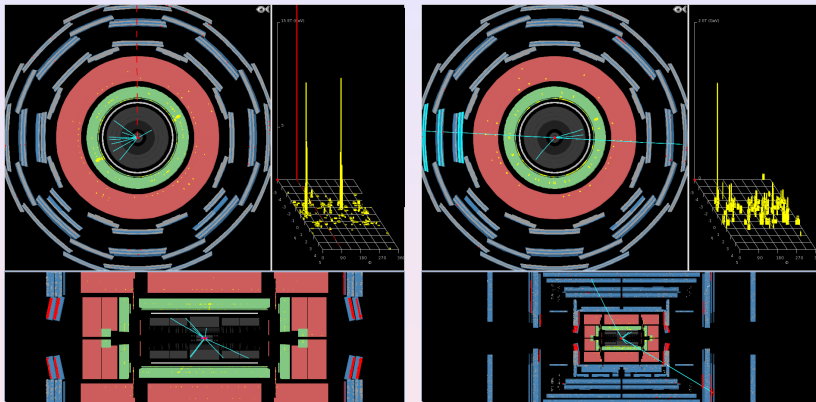


Physics background



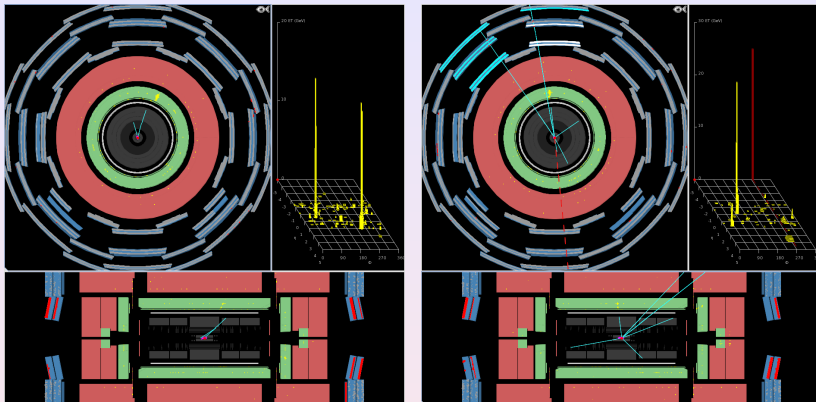
- Looking for rare decays (especially for Higgs) which are easily distinguishable from background

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)

OPlOT – MasterClass – Combination Page

Start Student Moderator Tutor Administrator

Wednesday, February 22nd 2017 - 10:08:19 CET

Moderator Tasks

2016 ▾ March ▾ 09 ▾

- Institute combination
 - Oslo
 - Athens
 - Faro
 - Poznan
 - Katowice
- Combination plot - all institutes
- Slides comparing results from previous IMCs with official ATLAS Results

Groups that have uploaded their files:

Athens
Group 1J
Group 1O
Group 1P
Group 1D
Group 1I
Group 1J
Group 1K
Group 1L
Group 1P
-
..

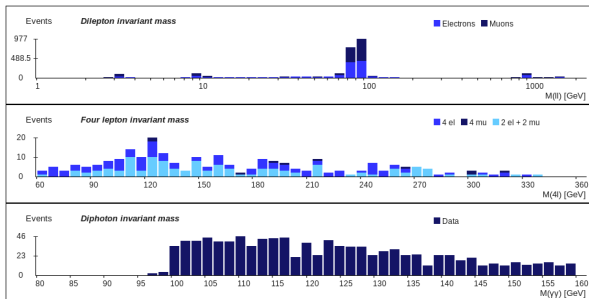
- Click “Moderator” (no password required)
- Select date
- You can see which groups have uploaded their results
- Click “Combination plot – all institutes” to see combined results for all uploaded data on the given date

Z path results from 2016

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

Start Student Moderator Tutor Administrator

Monday, February 20th 2017 - 13:38:51 CET



Bins:

Update plot

Reset

Plot type:

Dilepton statistics

Region	Electrons				
	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

Region	Muons				
	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

Number of events

Student distribution Expected	
ll	3118 4225
4l	347 40
yy	1092 1950
Sum	4557 6215

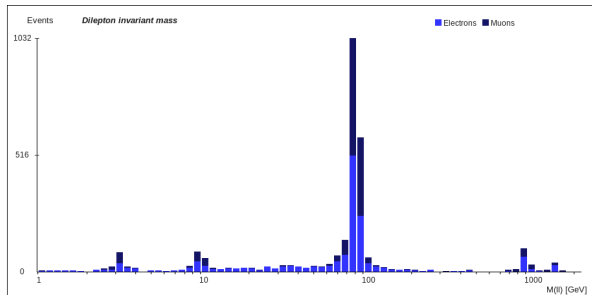
- “All institutes combination” start page
- Invariant mass distributions for all final states
- Table with estimated masses and widths
- Table with event counts compared to expectations

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



Bins:

X-Axis:

Upper:

Update plot

Reset

R1 Min:

R2 Min:

R3 Min:

R4 Min:

R5 Min:

R1 Max:

R2 Max:

R3 Max:

R4 Max:

R5 Max:

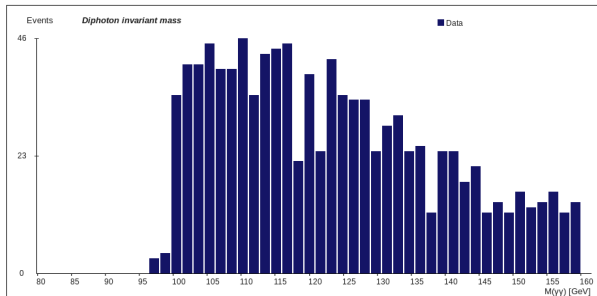
- Dilepton invariant mass distribution
- Can identify J/ψ , Υ , Z^0 , Z' , and graviton
- The latter two come as a surprise to the students (most likely already covered in the institute level review)

Z path results from 2016

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

Start Student Moderator Tutor Administrator

Monday, February 20th 2017 - 14:01:22 CET



Plot type:

YY

Signal and background (simulated data):

- No data
- 0.3514 fb⁻¹
- 2 fb⁻¹
- 10 fb⁻¹
- 25 fb⁻¹

Analyzed data (real data):

- No data
- Student distribution
- Expected distribution

Diphoton statistics

Diphotons	
Region	R
Events	25
Mean	1,515.13
Width	38.91

Bins: 50

Lower: 80

Upper: 160

Update plot

Reset

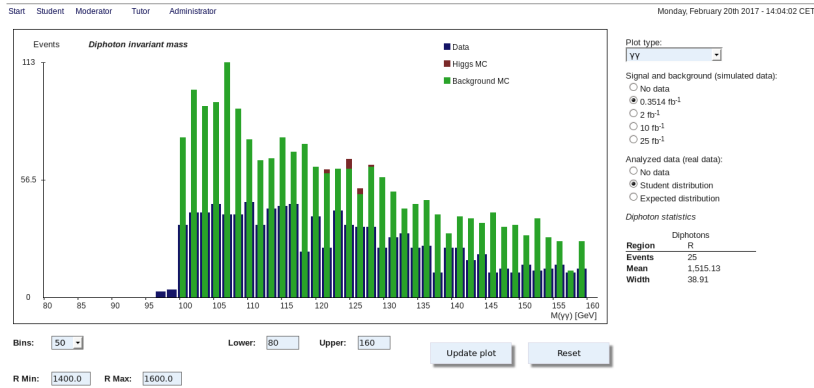
R Min: 1400.0

R Max: 1600.0

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

Z path results from 2016

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



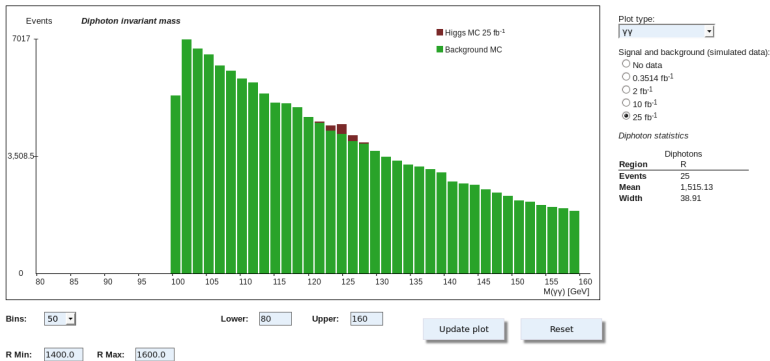
- Compare students' results to simulated background and signal corresponding to the analysed integrated luminosity

Z path results from 2016

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

Start Student Moderator Tutor Administrator

Monday, February 20th 2017 - 14:05:35 CET



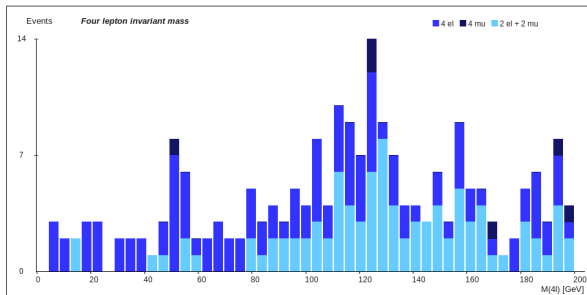
- Look at simulated background and signal for larger amounts of integrated luminosity
- ⇒ we could have seen the Higgs, we just need more data...

Z path results from 2016

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

Start Student Moderator Tutor Administrator

Monday, February 20th 2017 - 14:06:37 CET



Plot type:

4l

Higgs simulated data:

2 fb $^{-1}$

10 fb $^{-1}$

25 fb $^{-1}$

Analyzed data (real data):

No data

Student distribution

Expected distribution

4-lepton statistics

Region	R			
Event type	4l	4e	4m	2e+2m
Events	19	6	7	6
Mean	1,488.24	1,512.22	1,471.38	1,483.5
Width	44.86	43.31	40.18	41.08

Bins: 50

Lower: 0

Upper: 200

Update plot

Reset

R Min: 1400.0 R Max: 1600.0

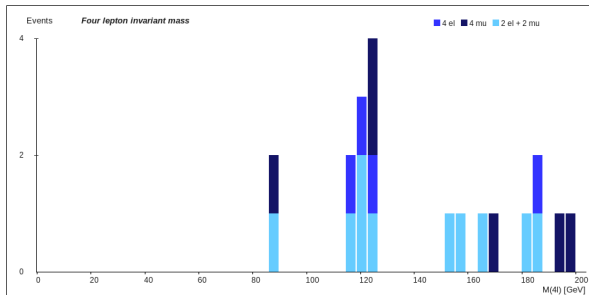
- 4-lepton invariant mass distribution
- Huge number of events (remember table in overview page)
- Notice composition in terms of $4e$, $2e2\mu$, 4μ
- Much easier to find fake electrons

Z path results from 2016

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

Start Student Moderator Tutor Administrator

Monday, February 20th 2017 - 14:14:08 CET



Plot type:
4l

Higgs simulated data:

- 2 fb⁻¹
- 10 fb⁻¹
- 25 fb⁻¹

Analyzed data (real data):

- No data
- Student distribution
- Expected distribution

4-lepton statistics

Region	R			
Event type	4l	4e	4m	2e+2m
Events	19	6	7	6
Mean	1,489.24	1,512.22	1,471.38	1,483.5
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Bins: 50

Lower: 0

Upper: 200

Update plot

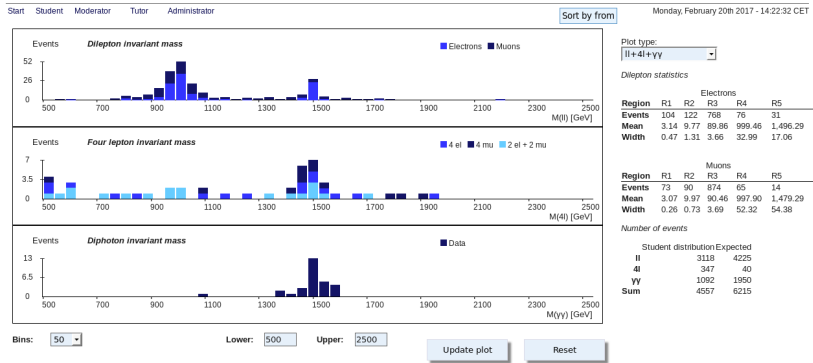
Reset

R Min: 1400.0 R Max: 1600.0

- 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

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



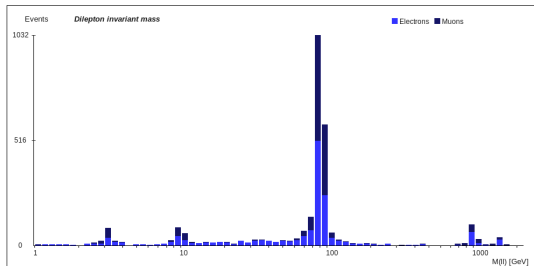
- Investigate high mass range in all final states simultaneously
- Z' seen only in dilepton distribution
- Graviton shows up in all of them!
- A manifestation of spin

Moderator “scenarios” (see [here](#))

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

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Electrons

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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

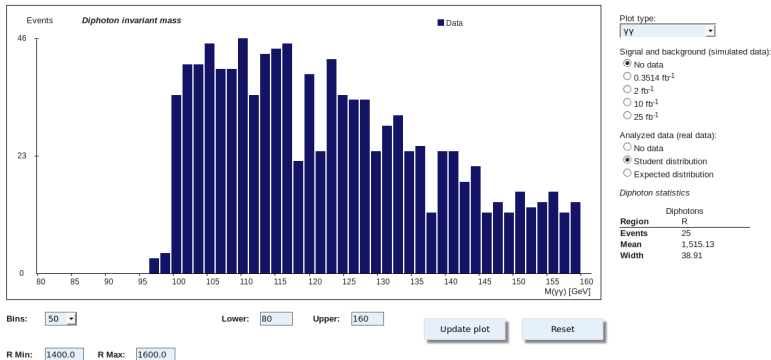
- Explain what a peak is, point out Z boson peak at 90 GeV
- **Poll question:** Do you see any peaks here that you would not expect?
- Discuss J/ψ and Υ , and explain that we “injected” Z' and graviton events at 1 TeV and 1.5 TeV

Moderator “scenarios” (see [here](#))

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

Start Student Moderator Tutor Administrator

Monday, February 20th 2017 - 14:01:22 CET



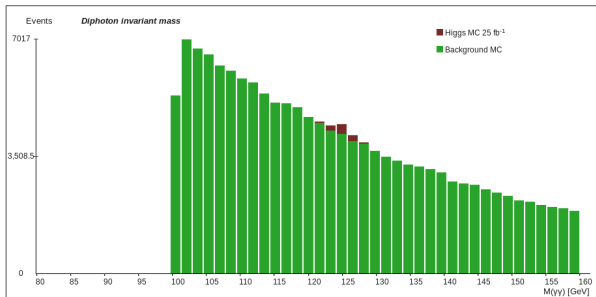
- **Poll question:** Do you see a peak corresponding to the Higgs boson?
- Explain about statistical limitations of the measurements and that $H \rightarrow \gamma\gamma$ is a very rare process

Moderator “scenarios” (see [here](#))

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

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Update plot

Reset

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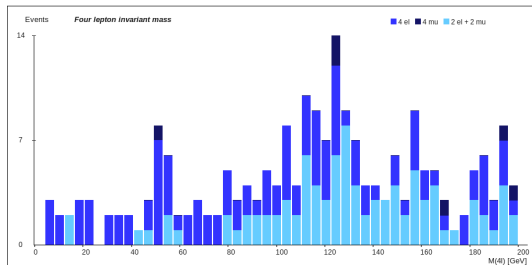
- Explain that you're now showing the results scaled up to a much larger amount of data
- **Poll question:** Do you think we could see the peak here even if it had the same color as the background?

Moderator “scenarios” (see [here](#))

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Update plot

Reset

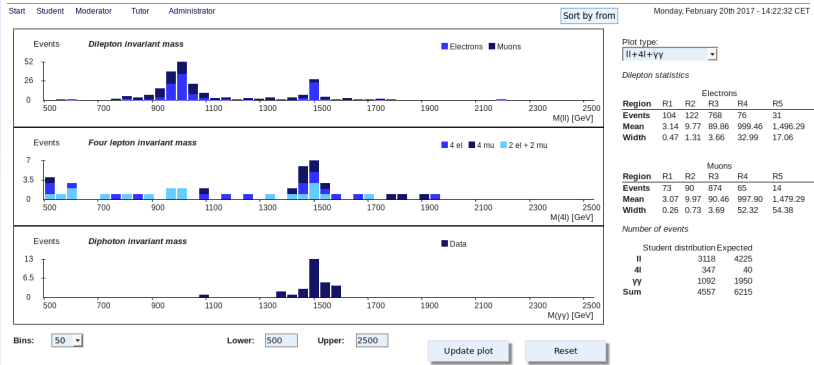
R Min: 1400.0

R Max: 1600.0

- Explain the plot and that we're now looking for Higgs bosons decaying to two Z bosons (with $Z \rightarrow ee$ or $Z \rightarrow \mu\mu$)
- **Poll question:** Why are there more events with electrons 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](#))

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



- **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

- Students look for dilepton, diphoton, and 4-lepton events to search for
 - $Z^0 \rightarrow l^+l^-$ (and other dilepton resonances)
 - $H \rightarrow \gamma\gamma$ (and other diphoton resonances)
 - $H \rightarrow l^+l^-l'^+l'^-$ (and other 4-lepton resonances)
- Invariant masses are calculated in HYPATIA and uploaded to OPlot
- 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