February 25, 2021

1 Notes/Timeline

Conventions:
file names of plots in the format: [Data set]_[cuts]_[quantity plotted]_[energy range]_[date dd-mm-yy]_[time (24 hr)].png

Notes:

- If you want to use a logarithmic scale when plotting a histogram in python then you use canvas.SetLogy(1) or canvas.SetLogx(1) depending on which axis you want to be logarithmic. 'canvas' is your TCanvas object

ROOT Notes

- lep_type values:

  11 = electrons

  13 = muons

- Units = MeV

Acronyms

- MC = Monte Carlo (Simulation)

1.1 Aims

- Establish Connection
- Set up Jupyter Notebook
-

1.2 Day Summary

09:00

Create shared overleaf document to share plots and lab notes:
https://www.overleaf.com/project/60251ee135265fbc62f06417
Exercise 6.1:
Derive a conversion from the kinematic variable set (p_T, ϕ, η) to (p_x, p_y, p_z)

$$\ldots \tag{1}$$

Exercise 6.2:
Derive an expression for m_{ll} for the the decay $Z \rightarrow \mu^+\mu^-$.

$$\ldots \tag{2}$$

http://opendata.atlas.cern/release/2020/documentation/datasets/dataset13.html

9:20 - Lead DG

Logging onto manchine 3.

9:30

Set up Jupyter notebook on lab machine 3, Password: Atlasfp423.

10:00 - Lead BG

10:07

Issue in 5.2: access denied when specifying language

10:24

Resolved: There was a temporary conflict on the machine

11:42

Issue in 5.3 (3&4): Token not provided, Tried on both computers- still no change.

12:14

Issue in 5.3(7): Incorrect page in web browser (Only shows password).
Resolved: New machine used (mu=3) (changed to mu=17).
ssh string:

```
ssh -N -L localhost:1234:localhost:8888 atlaslab17@atlaslab17.blackett.manchester.
ac.uk
```

14:00 - Lead: DG

15:00 - Lead: BG

16:00

Exploring Analysis.py and LabNotebook.ipynb

17:00

Log off for the day.

11/02/2020

09:20 - Lead DG

(Exercise 6.4) Plotting the invariant mass using Zmumu MC data
Error in "Analysis.py" - null pointer "hinvmassZll.Write()" Remove all unnecessary code

10:56

Narrowed error down to ".setAlias" string

11:00

Error Found: missing bracket and not using lowercase functions.
Success at plotting the sum of pT (transverse momenta) of the Z boson using MC $Z \to ll$ data (Z). Can be seen in Fig.**??**

11:12

Success plotting the invariant mass of the Z boson using MC $Z \to ll$: figure.**??**
From MC:
Mean: $(9.018 \pm 0.766)e + 4MeV$
$Expected$: $(9.1187 \pm 0.00021)e + 4MeV$

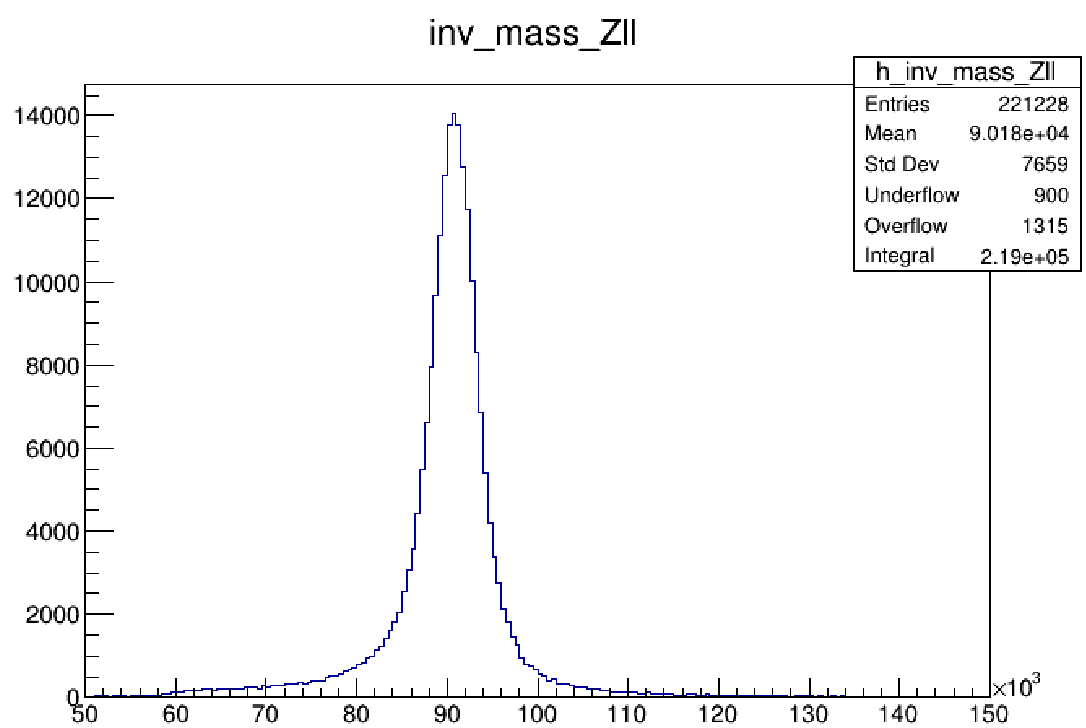


Figure 1: Plot of $Z \to ll$ invariant mass using MC data. From MC: Mean = (9.0180.766)e+4 MeV. Expected: (9.11870.00021)e+4 MeV

11:50 - Lead BG

Notes/thoughts:

13:00

Break for lunch

14:00 - Lead DG

Working on exercise 6.7:
Plot graphs of ptcone30 and etcone20 for leptons that are same flavour, oppositely charged. (Zee, Zmumu, 2lep)

ptcone30 = scalar sum of track p_T in a cone of R=0.3

Create new function 'Ptcones' in "Analysis.py" to plot the Ptcone30 of a specific lepton.

15:10

To start plot ptcone30[0]:
First plot - figure.**??** of large range (0-4 GeV).
Data point at 0 GeV then a gap in data to 1 GeV due to. an artifact of the data of 0 - 1 GeV not being detected.
Would have expected an exponential decay.

16:00 - Lead BG

16:11

Question:
Why is there not lep_type = tau?? Plotting the **invariant mass** of ATLAS experimental data for at least 2 leptons with cuts to select for individual decay paths over energy range 0-150 GeV

- $Z \to ee$ (lep_type = 11 && 2 particles opposite charge)
- $Z \to \mu\mu$ (lep_type = 13 && 2 particles opposite charge)
- $Z \to \tau\tau$ (Non ee and non $\tau\tau$)

Running e-e pair which is oppositely charged. Figure.2
Running mu-mu pair which is oppositely charged
Running non e-e and non mu-mu pair which is oppositely charged returned plot no tau-tau pairs with opposite charge

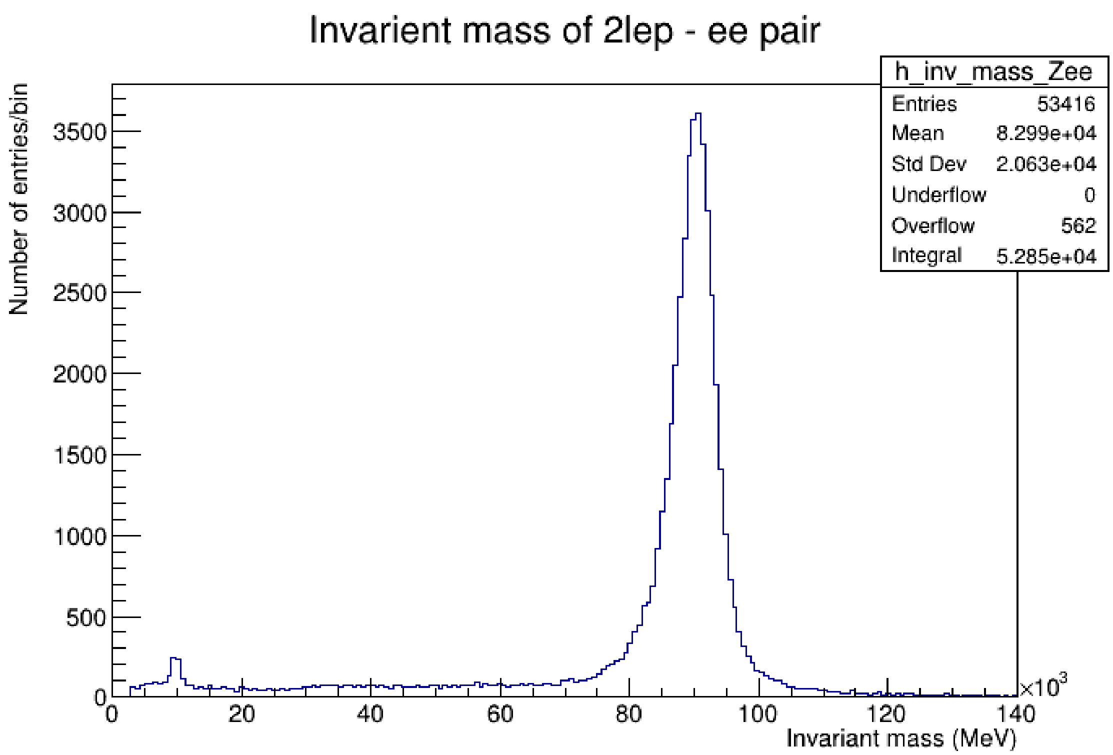


Figure 2: Plot of $Z \to ll$ pTcone30 using MC data.

16/02/2020

09:00

Discussion of plan for the day:

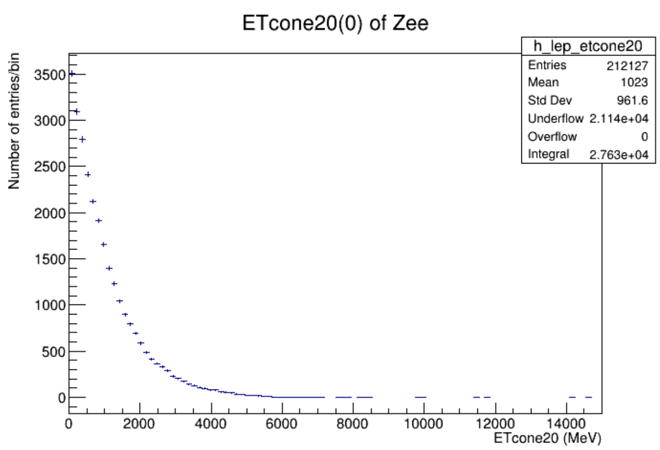
- Finish plotting $Z \to ll$ plots
- Apply cuts to pTCone30 plots
- etCone20 plots

09:23 - Lead DG

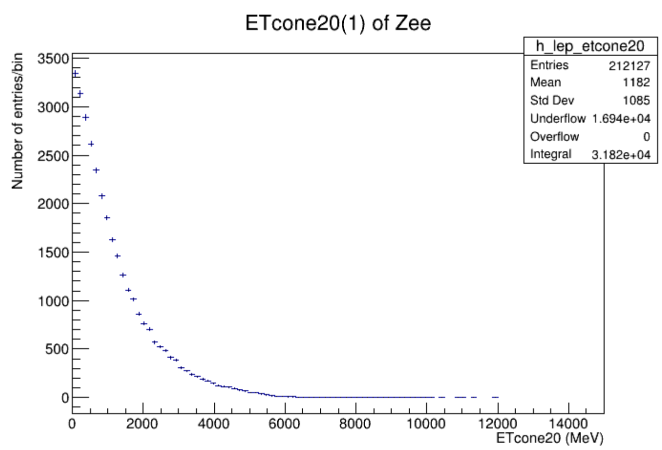
Plot etcone20 to investigate what data is available.
Figure.**??**

plots Fig.**??** of the etcone20(1)

Both fig.**??** and fig.**??** are similar with a larger mean value for fig.**??**.
Noticed a "bump" at around 4 GeV.
Plan to plot the log of the data to investigate if decay is related to exponential decay.



(A)



(B)

Figure 3: (A) Plot of $Z \to ee$ ETCone20(0) for Zee-fast MC data. (B) Plot of $Z \to ee$ ETCone20(1) for Zee-fast MC data.

09:53

Plotting the ETCone of each of the two leptons produced from the decay of $Z \to \mu\mu$ using the MC data. On fig4 a slight "bump" at around 1.9 GeV

On fig.5 the

10:07

Plotting the pTCone30 (0)&(1) of $Z \to ee$ for the range of 1-4 GeV. This range is used due to 0-1 GeV not being detected. (See 11-02-2021 for the investigation and plots of the full energy range.)

On fig.6, the number of entries decrease exponentially as momentum increases. There is also a "bump" around pTcone30 = 2.25GeV

In fig.7 to "bump" seen is not as pronounced as in fig.6.

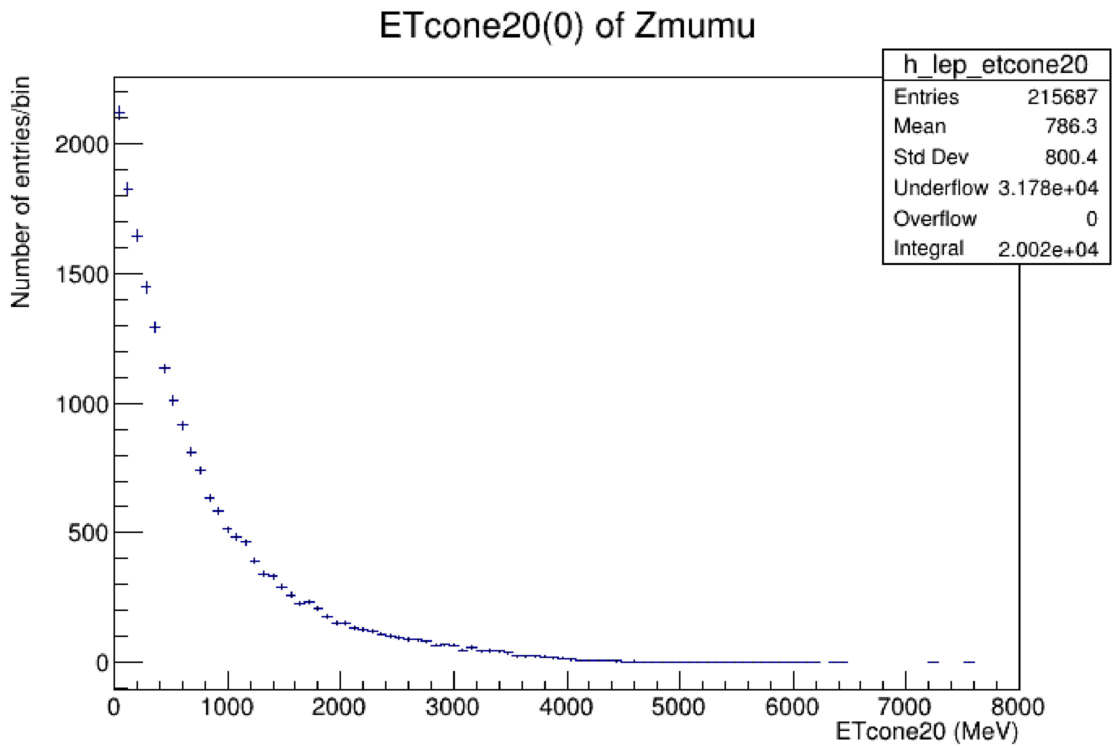


Figure 4: Plot of $Z \to \mu\mu$ ETCone20(0) for $Z\mu\mu$-fast MC. data.

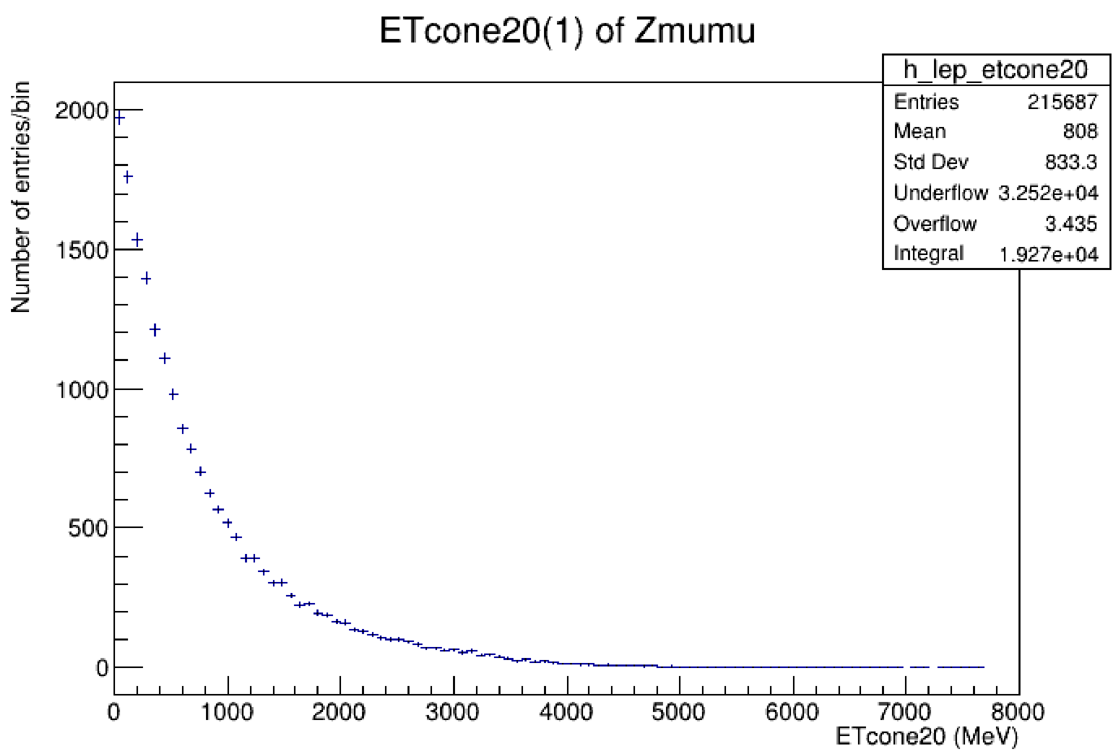


Figure 5: Plot of $Z \to \mu\mu$ ETCone20(1) for $Z\mu\mu$-fast MC. data.

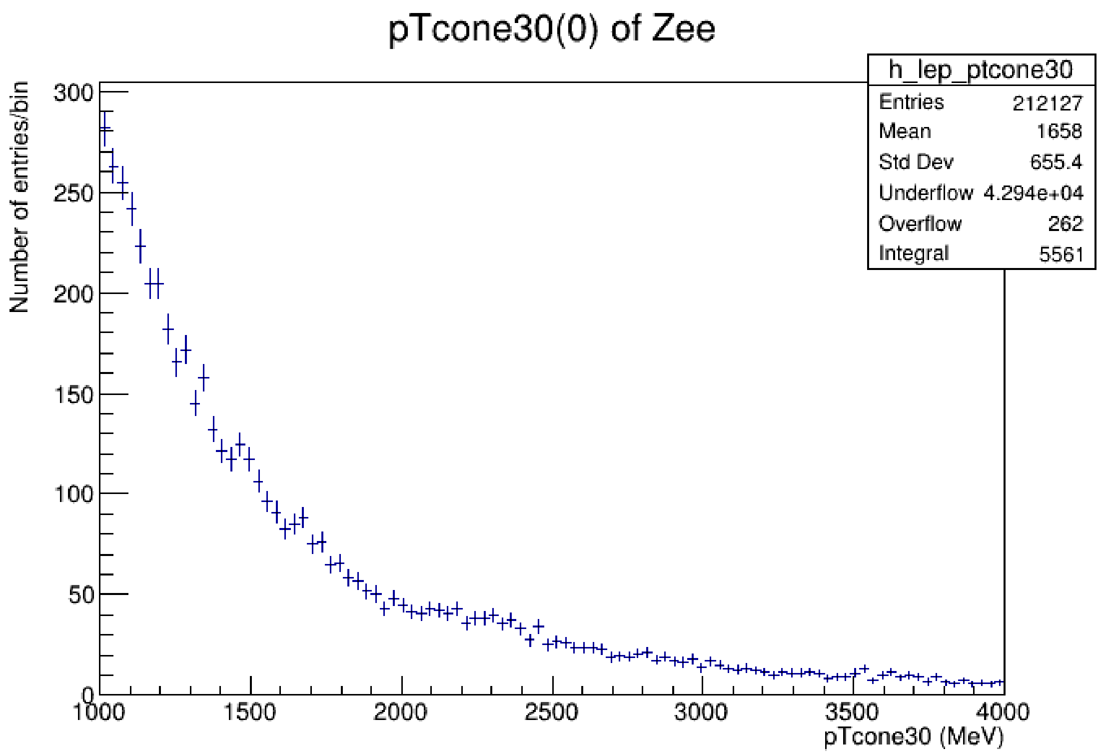


Figure 6: Plot of $Z \to \mu\mu$ pTcone30(0) for $Z \to ee$-fast MC. data.

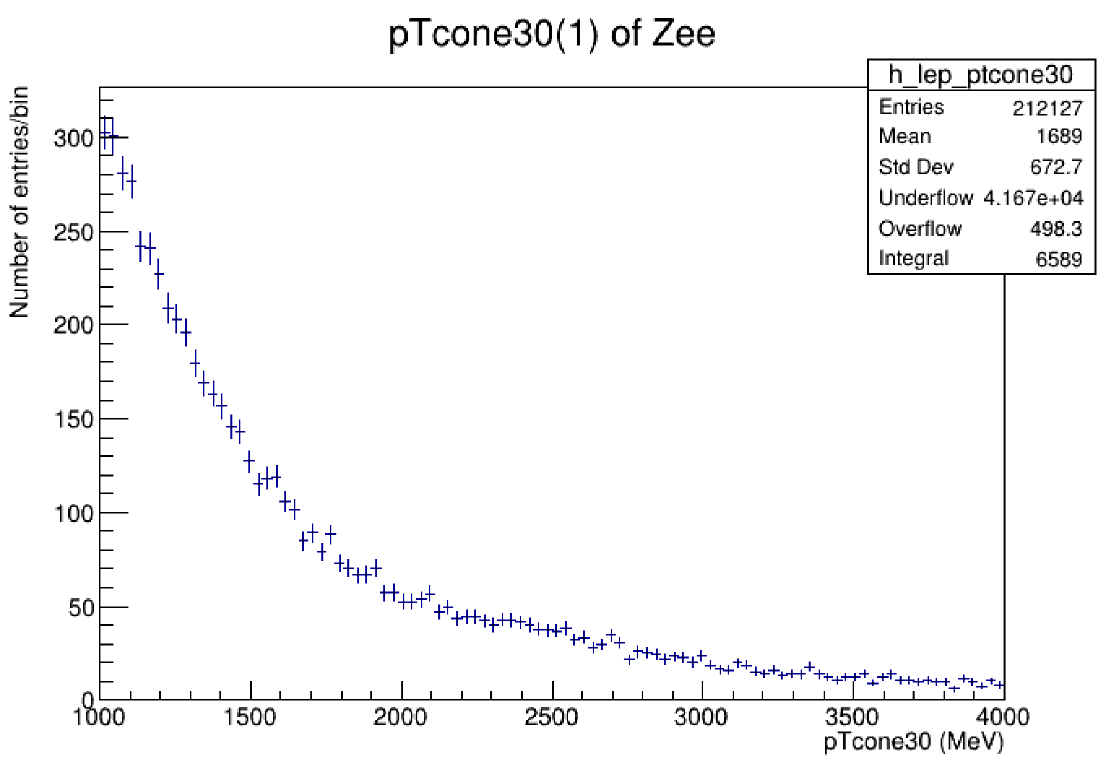


Figure 7: Plot of $Z \to \mu\mu$ pTcone30(1) for $Z \to ee$-fast MC. data.

10:18

Plotting the pTCone30 (0)&(1) of $Z \to \mu\mu$ for the range of 1-4 GeV. This range is used due to 0-1 GeV not being detected. (See 11-02-2021 for the investigation and plots of the full energy range.)

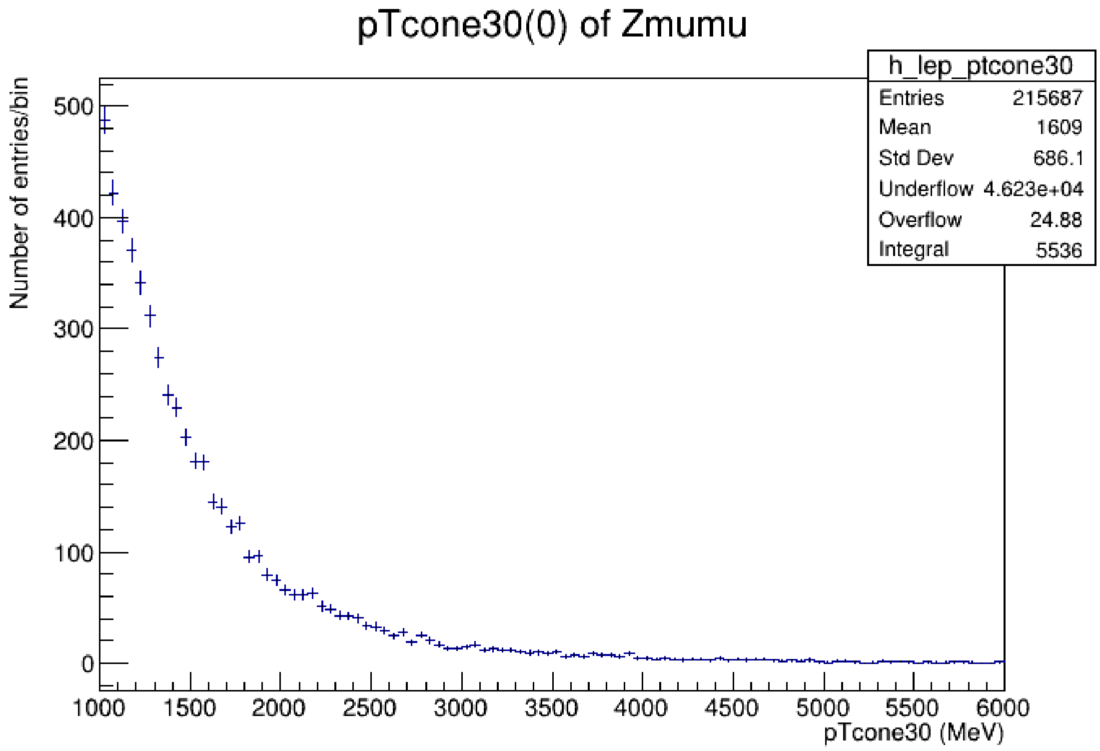


Figure 8: Plot of $Z \to \mu\mu$ pTcone30(0) for $Z\mu\mu$-fast MC. data.

10:40

Plotting the pTcone30 (total (sum of the two leptons)) of ATLAS data with cuts:

- opposite charge
- lep_type == 11 (lepton type = electron)
- lep_n == 2 (number of leptons = 2)

To start, plot the range of 0-10 GeV to show 0-1 GeV is not detected. This is seen in Fig.10 with a peak value at (total) pTcone30

Fig.11 has the range set to 1-6 GeV (to remove the un-detected regoin 0-1 GeV). This still shows exponential like decay as pTcone increases.

The "bump"/inconsistency (if expecting smooth exponential like decay) is present in the experiental ATLAS data around 2-2.7 GeV. To investigate this bump, plan to plot the invariant mass with a cut to select for a pTcone30 in the vicinity of 2-2.7 GeV.

11:10

Plotting ATLAS 2lep data for the total ETCone20 for a ee pair in the range of 0-6 GeV. This can be seen in Fig.12

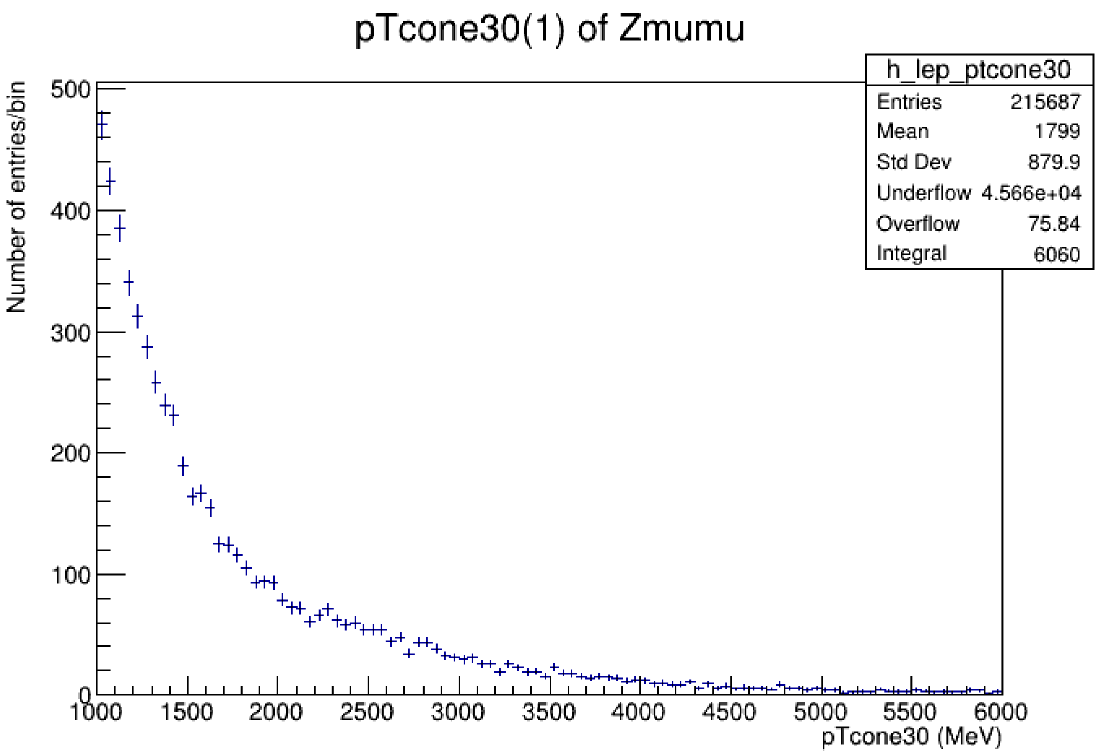


Figure 9: Plot of $Z \to \mu\mu$ pTcone30(1) for $Z\mu\mu$-fast MC. data.

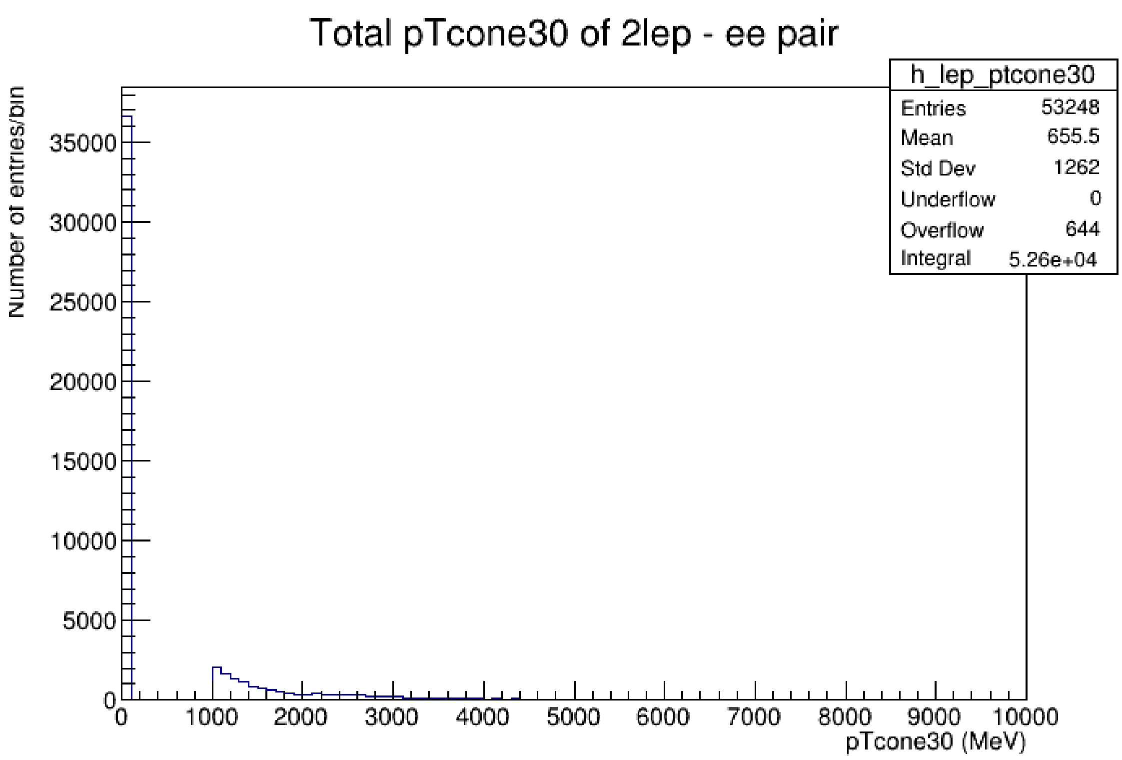


Figure 10: Plot of $Z \to \mu\mu$ pTcone30(1) for $Z\mu\mu$-fast MC. data.

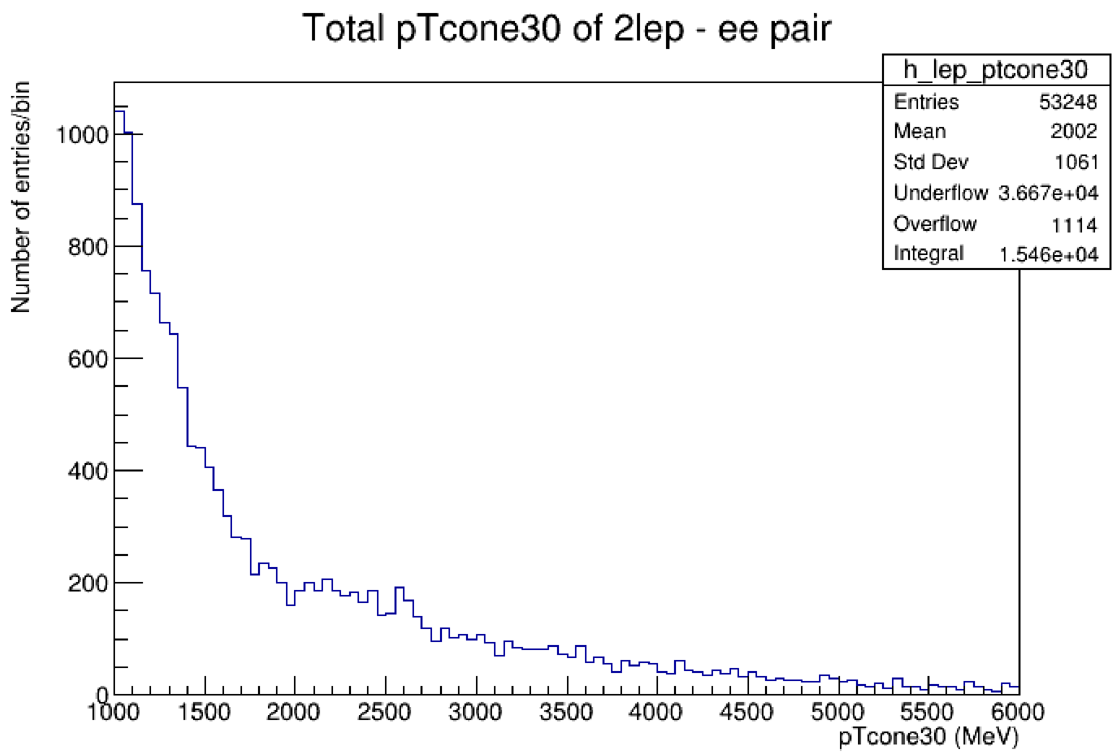


Figure 11: Plot of $Z \to \mu\mu$ pTcone30(1) for $Z\mu\mu$-fast MC. data.

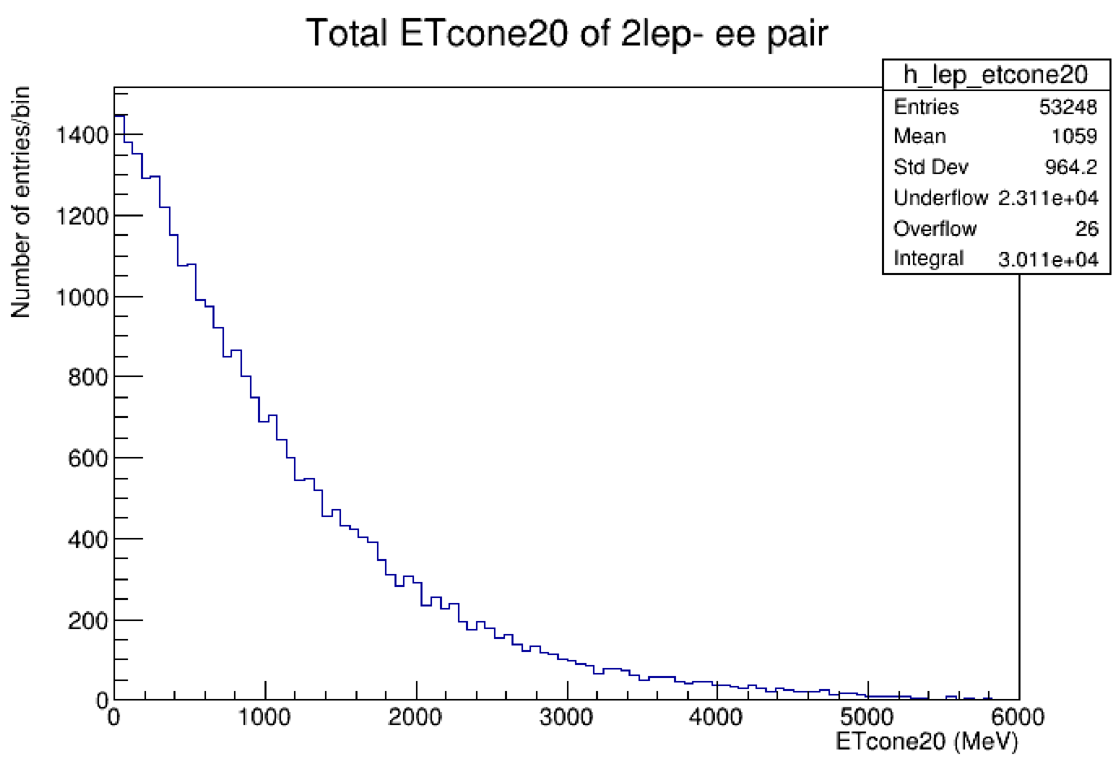


Figure 12: Plot of the total ETCone20 of an ee pair using the 2lep-fast ATLAS data. data.

11:14

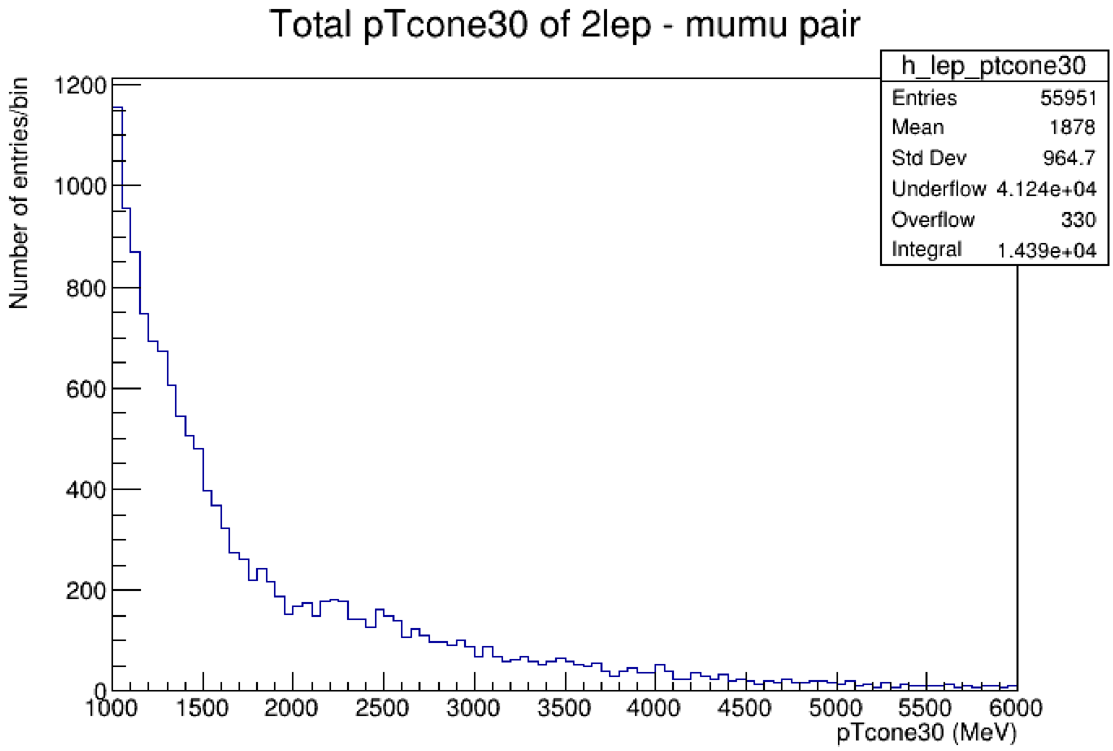


Figure 13: Plot of the total pTcone30 of a mumu pair using the 2lep-fast ATLAS data.

11:24 - Lead BG

To investigate the possible bump or dip (as seen in the pTcone30 data (bump around . . . or dip around . . .)) plot the log of the ptCone30.

14:06- BG lead

Investigate use of stacked MC plots to identify background when comparing to ATLAS data.//

14:50

Stacked plot made for invariant. mass

16:20

Stacked plot made for mean etcone20, includes

- 2lep data
- Zee MC
- Zmumu MC
- Ztautau MC

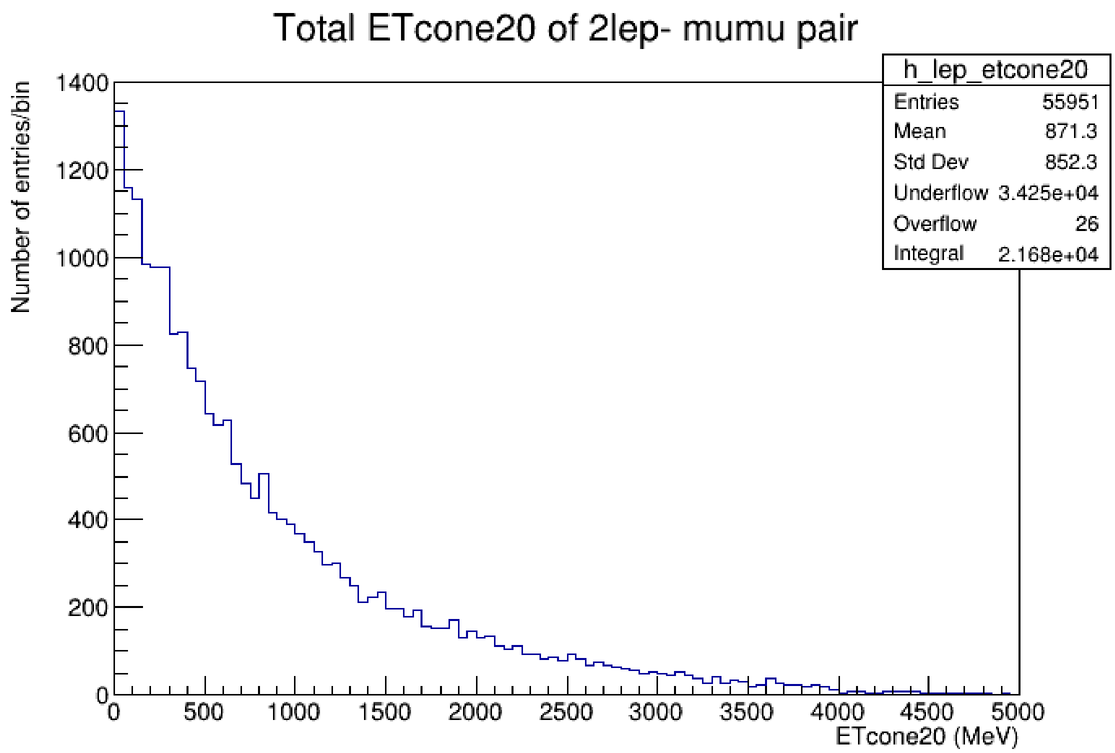


Figure 14: Plot of the total ETcone20 of a mumu pair using the 2lep-fast ATLAS data.

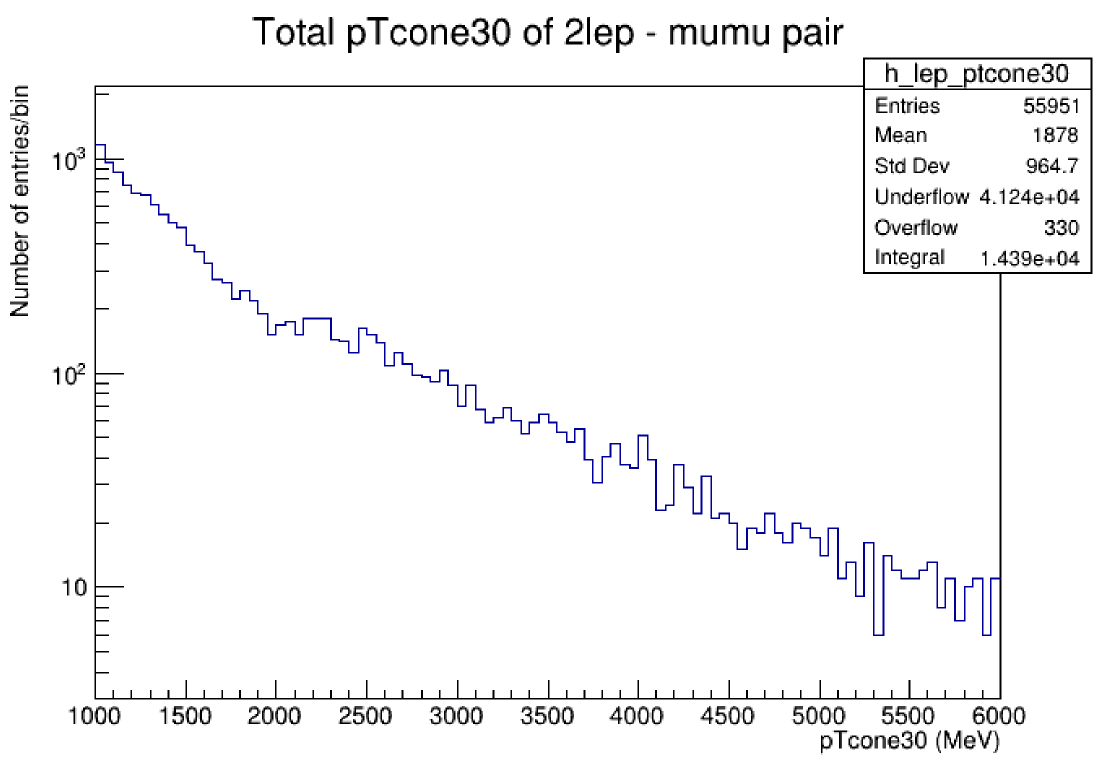


Figure 15: Plot of the total pTcone30 of a mumu pair using the 2lep-fast ATLAS data, log.

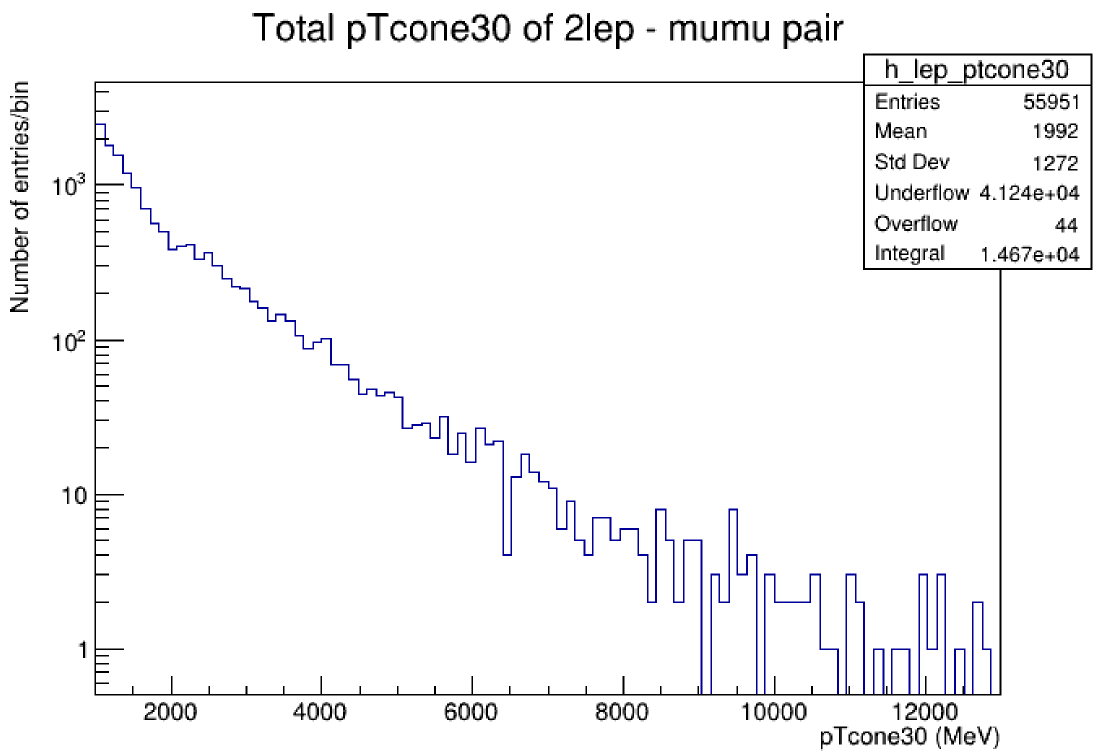


Figure 16: Plot of the total pTcone30 of a mumu pair using the 2lep-fast ATLAS data, log,1-13GeV.

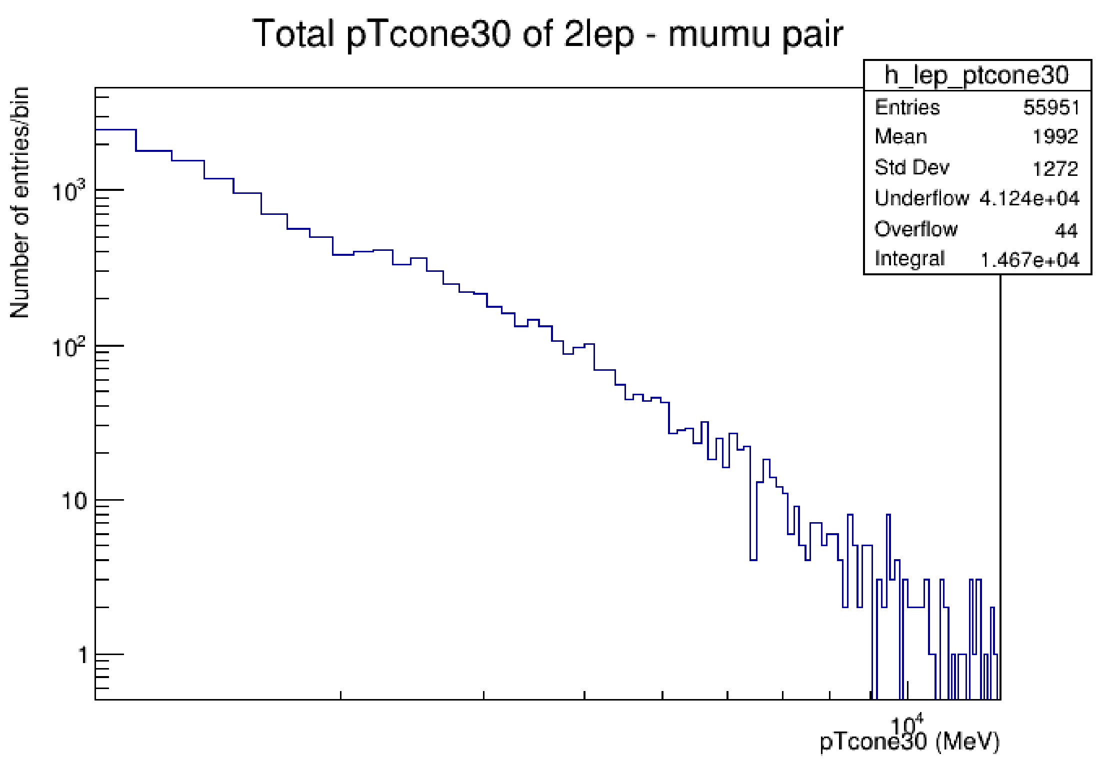


Figure 17: Plot of the total pTcone30 of a mumu pair using the 2lep-fast ATLAS data, log-log,1-13GeV.

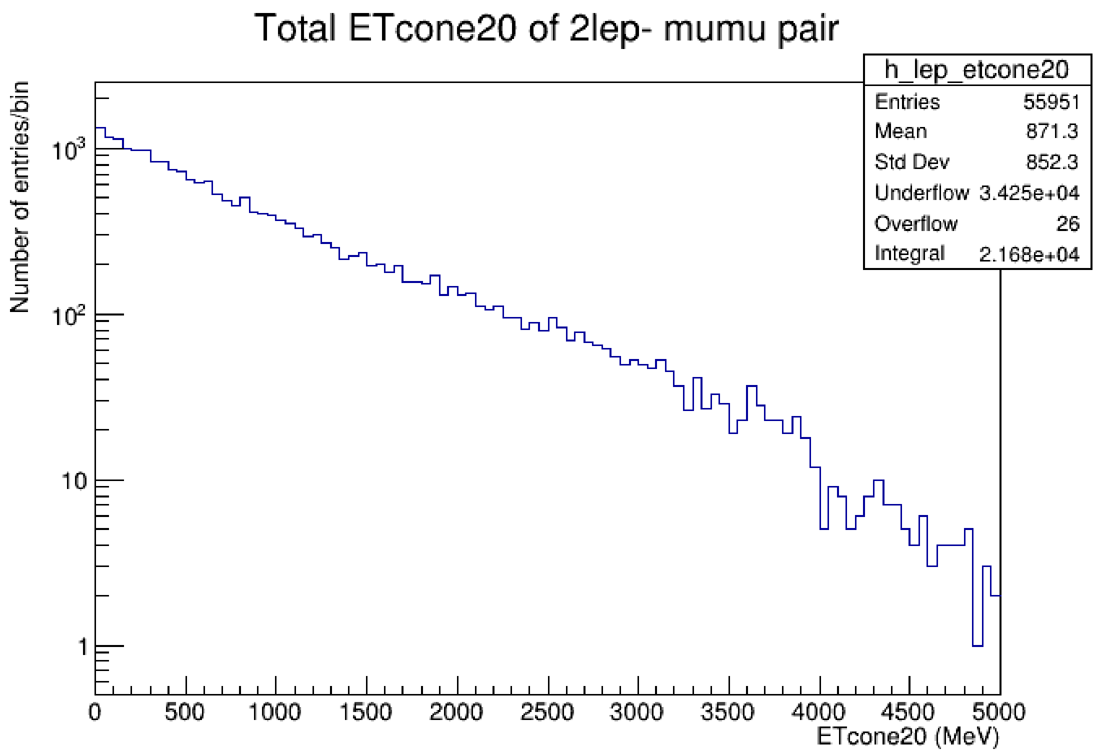


Figure 18: Plot of the total ETcone20 of a mumu pair using the 2lep-fast ATLAS data, log, 0-5GeV.

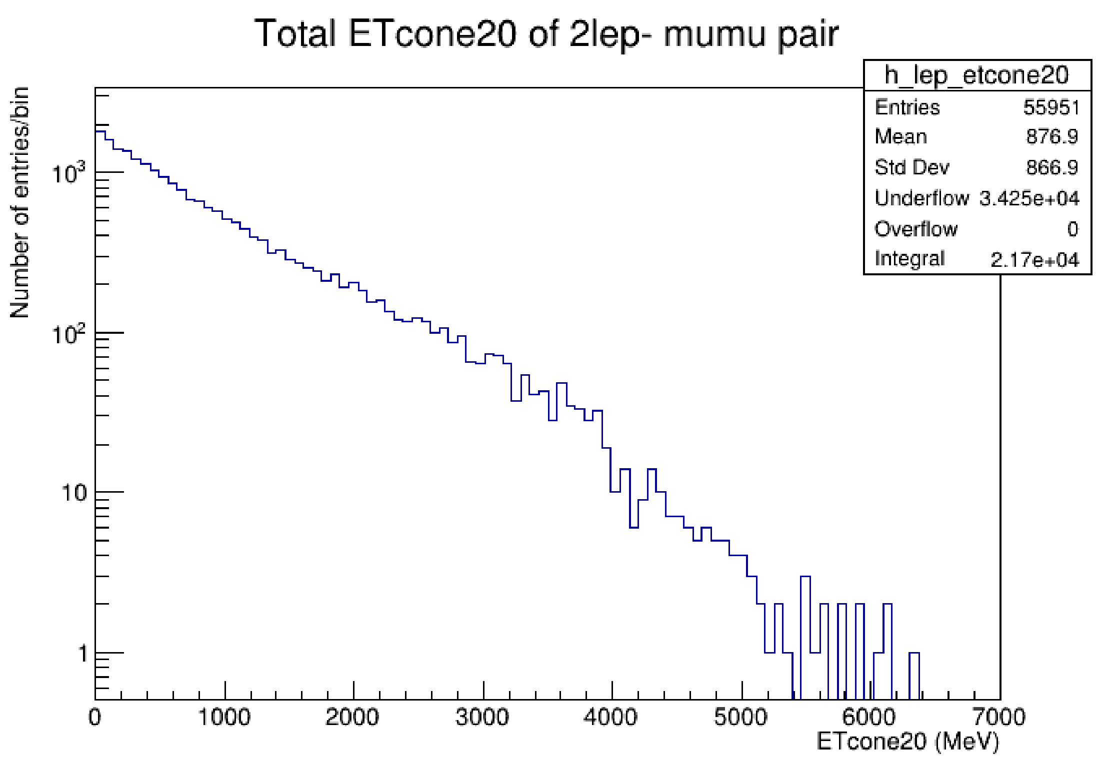


Figure 19: Plot of the total ETcone20 of a mumu pair using the 2lep-fast ATLAS data, log,0-7GeV.

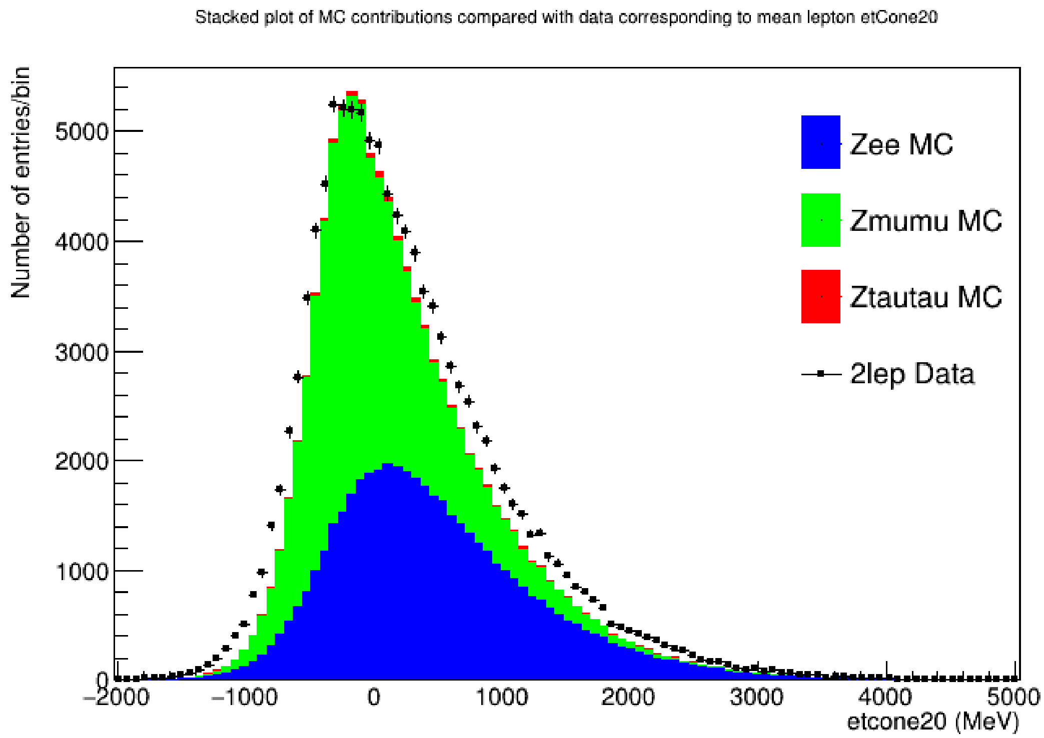


Figure 20: Stack plot of the mean ETcone20 of 2 lep with opposite charge pair using the 2lep-fast ATLAS data, log,0-7GeV.

16:28

Unexplained discrepancy of 2lep data around peak 0MeV (Fig.20)

18/02/2020

09:00 - Lead BG

Discussion on how to calculate cross section of a process:
Integrated Luminosity = 139fb^{-1}($\pm$1.7%)
Coeficient ϵ given by sum of MC signal weights over that for relevent sample (found using TotExpected.Py)

09:30

Make stacked plots for pTcone30 and etcone.

09:41

Plot the

Add ttbar_lep background to stack plots.
$\epsilon_{\text{Zee}} = 19630128.89$
Quoted value for Zee cross section $76.0 \pm 0.8 \pm 2.0 \pm 2.6$ pb (https://arxiv.org/pdf/1212.4620.pdf)

10:38

Rough estimate for the cross section: $\sigma(pp \to Z \to ee)$ is given by:

$$\sigma = \frac{N^{selected} - N^{background}}{\epsilon \int Ldt} \tag{3}$$

where

$$\epsilon = \frac{\sum \text{weights for all MC events which pass selection cuts}}{\sum \text{weights for all events for that process}} \tag{4}$$

For $Z \to ee$ use the cuts:

- lep_n = 2
- same flavour/type (lep_type [0] == lep_type[1])
- opposite charge (lep_charge [0] != lep_charge[1])
- invariant mass ¿ 60 GeV

  MC not modelled below this point

For $\sigma(pp \to Z \to ee)$:

- $N^{selected} = 47531$
- $N^{background} = 0$
- $\epsilon = \frac{46740}{19630128.89} =$
- $\int Ldt = 10.064\mathbf{fb}^{-1}$

cs = 1.9835391029941325e-09
Other sources of background - photon conversion - hadronic jets -W or t decays can be detected as 2 electrons or muons when one is in fact a hadron jet or electron/moun from other source.

14:00 - Lead DG

Investigating the decay paths of W-plus and W-minus

There is an exponential decay in the number of leptons apart from a bump at ....

14:40

Plot the invariant mass between 60-150GeV for Wplus_2lep for events that would look like $Z \to ll$.
Large underflow, so increase range to 0-150 GeV
Still not totally decayed, increase range to 0-500 GeV
Take the log of y-axis

16:00 - Lead BG

Finding the background contributions from $W^+ \to l\nu_l$ with the cut

```
lepCut ="(" + "(lep_charge[0] != lep_charge[1]) && (lep_type[0]==11 && lep_type
    [1]==11) && lep_n==2 && (inv_mass_Zll > 60e3) && (inv_mass_Zll < 115e3)" + ")"
```

to select for e+e- pair.

$$N_{t\bar{t}}^{background} = 236276 \tag{5}$$
$$N_{W^+}^{background} = 2247 \tag{6}$$
$$N_{W-}^{background} = 1785 \tag{7}$$

Sum of all weights for all MC events which pass cuts for Zee:

$$= 4595000$$

4817004
$\sigma(Z \to ee) = 1.94275964340403e - 09b$
TODO:

- Plot $\Delta\phi$
- ϵ cut

23/02/2020

08:30 - Lead BG

The ATLAS detector can mistake the production of a l^+l^- pair from 2 separate decays as pair production from the decay of a single particle, such as a Z boson.
The most probable source of this is from W boson decays:

$$W^+ \to l^+\nu_l$$
$$W^- \to l^-\bar{\nu}_l$$

to be mistaken for $Z \to ll$.
In the case of $Z \to ll$, the two leptons would be expected to be produced with the angle between them $(\Delta\phi) \approx \pi$ (angle between the azimuthal angle) to conserve momentum.
Counter to this, the $W^+ \to l^+\nu_l$ and $W^- \to l^-\bar{\nu}_l$ can be proceed at any angle, so would expect production to include $\Delta\phi \approx 0$
To investigate this, plot $\Delta\phi$ of ATLAS "2lep" data with the cuts such that - Fig.21

Fig.21 shows that there is a small peak at lower angles. This can be produced from. two main processes:

- Momentum conservation to compensate for jets
- incorrect classification for two W+ and W- decays.

Cuts used in Fig.21:

```
lepCut = "(" + "(lep_charge[0] != lep_charge[1]) && (lep_type[0]==lep_type[1]) && lep_n
    ==2" + ")"
```

Plot the difference between the lepton pair as a stack plot to compare MC and ATLAS data.
Cuts used in Fig.22:

```
lepCut = "(" + "(lep_charge[0] != lep_charge[1]) && (lep_type[0]==lep_type[1]) && lep_n
    ==2" + ")"
```

Plotting the same data with the same cuts as for Fig.21 in the form of a stack plot to show expected contributions from signal and background sourced using MC data.

09:48 - Lead DG

Apply ptcone20 cut on invariant mass plots.
Since there is no distinction between events in the range 0-1 GeV, cut events above 1 GeV.
Since variables/quantities are correlated (can be effected by the same physical process), plot the etcone20 stack plot. See Fig.**??**

12:21

Plot

14:07 - Lead BG

Plot pT log to test for potential cuts.
Test other kinematic variables to look for potential cuts
Upper bound cut of 320GeV for total lepton pair pT. See Fig.

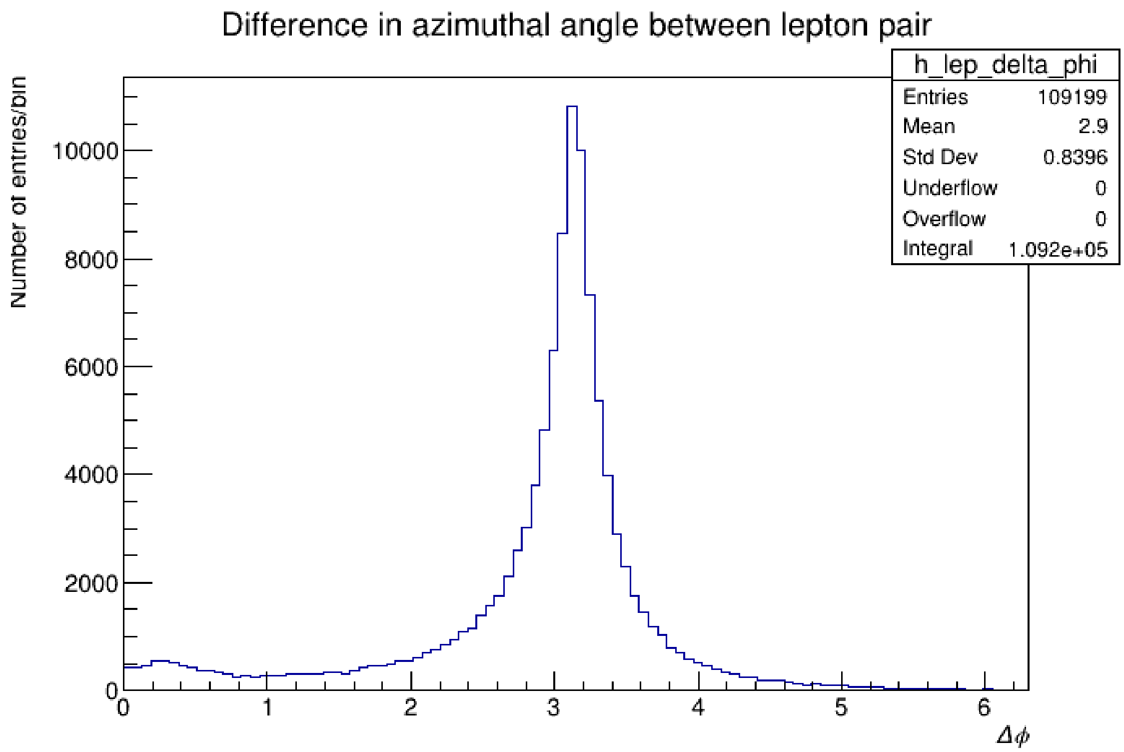


Figure 21: The difference of the azimuthal angle of the lepton pair for ATLAS data. The main peak at approx π is as expected. Cuts: (lep-charge[0] != lep-charge[1]) && (lep-type[0]==lep-type[1]) && lep-n==2

Figure 22: The difference of the azimuthal angle of the lepton pair for ATLAS data with MC data stacked (included main MC simulated background and source). The main peak at approx π is as expected. Cuts: (lep-charge[0] != lep-charge[1]) && (lep-type[0]==lep-type[1]) && lep-n==2

(A) (B)

Figure 23: (A) (B)

15:24 - Lead DG

Plot eta in search of potential cuts.
Decide on upper cut of $\eta - 2.5$ using Fig.**??**

15:31

Plot the stack plot of delta phi in search of possible cuts.
First apply only minimal cuts (no lower from invariant mass and upper):

```
...
```

From Fig.24: - Inconstancy between MC and ATLAS data around 0-1 rad.

Now add upper from total transverse momentum and lower from invariant mass. From Fig.**??**: -¿ Good MC fit to ATLAS data - no more ”bump” between 0-1 rad

Question: Is it better to make cuts based on individual particles or total/mean.

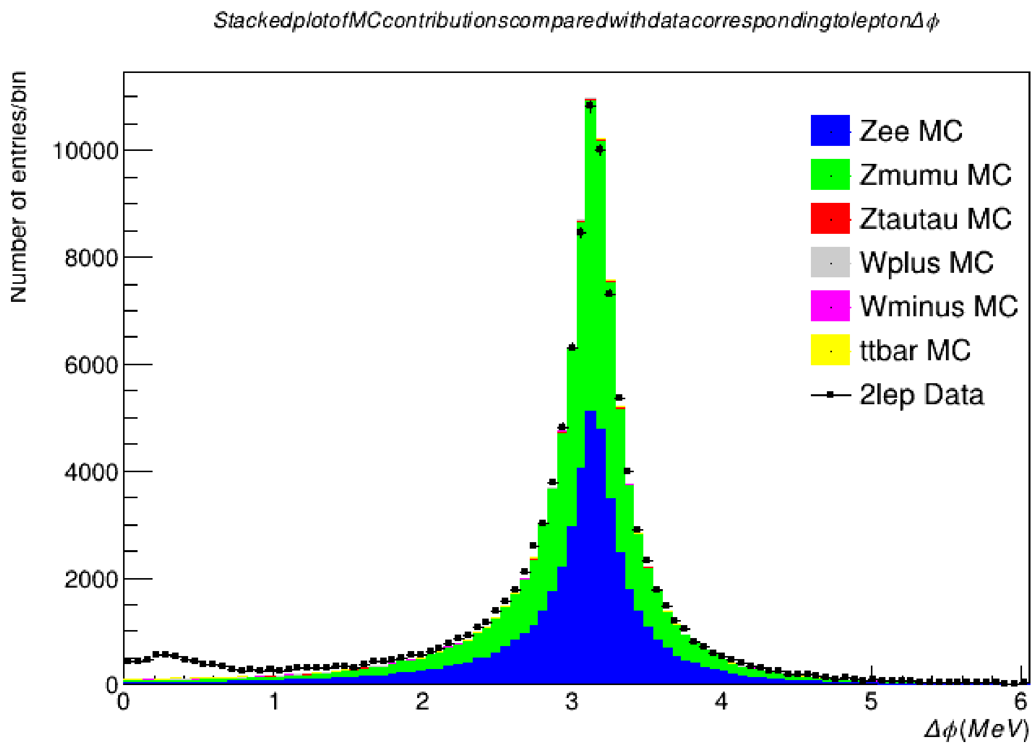


Figure 24: Stack plot of delta phi with only minimal cuts to select for events with 2 leptons of same type with opposite charge. There is an inconsitancy between MC and ATLAS data

Figure 25: Stack plot of delta phi with only minimal cuts to select for events with 2 leptons of same type with opposite charge. There is an inconsitancy between MC and ATLAS data

15:54 - Lead BG

Start to calculate the cross section of $pp \to Z \to ee$ with the new cuts (lower and upper bounds on variables).
Cuts being used:

```
lepCut ="(" + "(lep_charge[0] != lep_charge[1]) && (lep_type[0]==lep_type[1]) && lep_n
    ==2 && (inv_mass_Zll > 60e3) && (lep_pt[0]+lep_pt[1]) < 320e3 " + ")"
```