# Measuring the W Mass

## Semi Leptonic Kinematic method

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# Intro

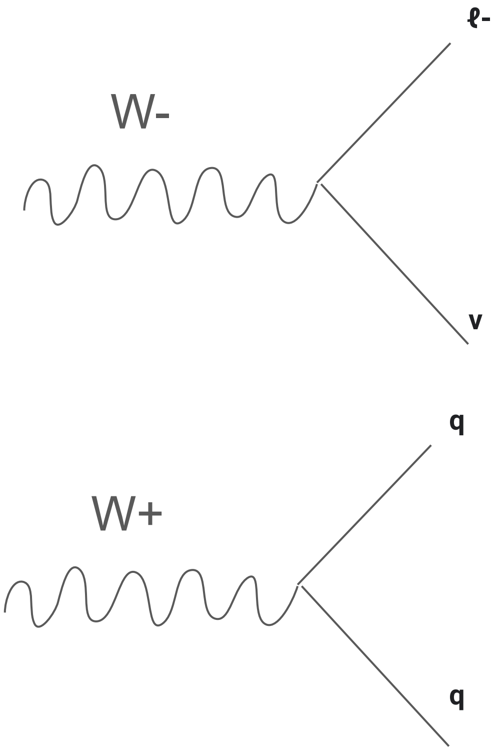
- The W boson is the carrier of the weak force and its mass is an important parameter in the standard model.
- The current value is 80.379 GeV +/- 12 MeV.
- The Collider Detector at Fermilab measurement was 7 standard deviations higher than the value predicted by the standard model, suggesting new physics contributing to the mass.
- This created a huge controversy, sparking a new effort to accurately measure the W mass.
- At FCCee, the precision could be lowered to 1 MeV which would help in developing an explanation for the current discrepancy.

# Intro cont.

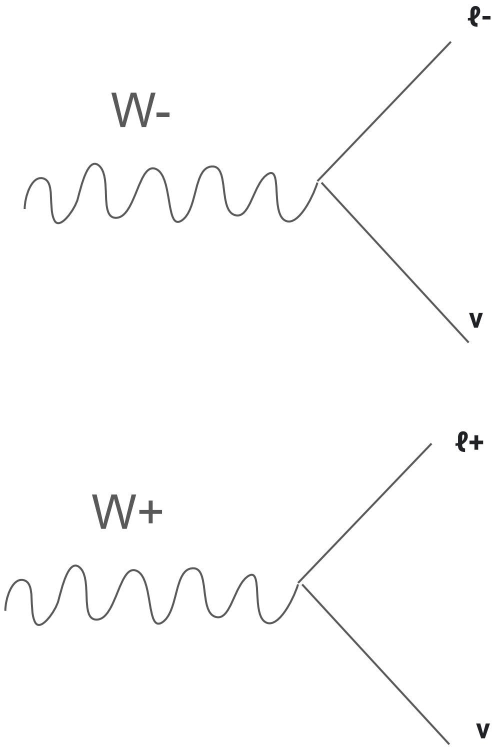
- In this project, we measured the W mass by measuring the W decay products.
- W bosons are produced in pairs (W+W-) in electron-positron collisions.
- Each W boson can decay hadronically (qq) or leptonically (l+nu).

# Feynman Diagrams

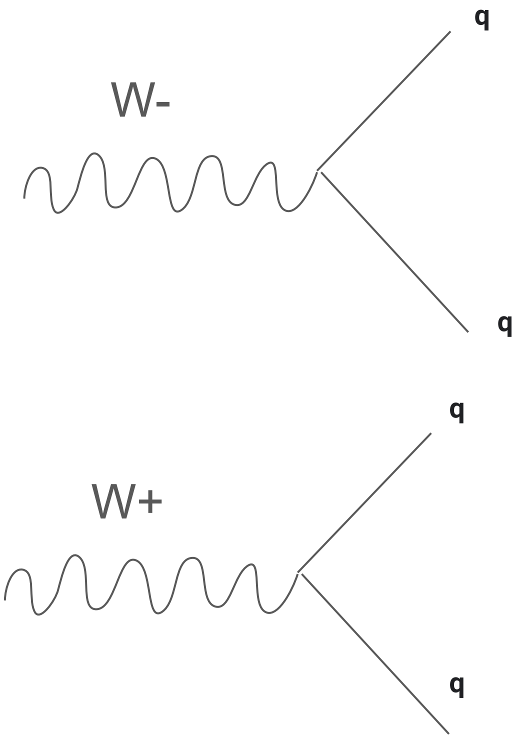
## Semi Leptonic



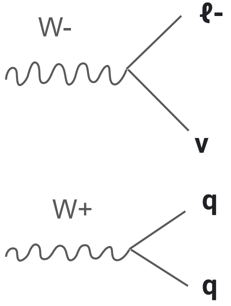

## Fully Leptonic




## Fully Hadronic



# Procedure

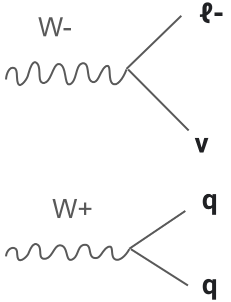



We're measuring the invariant mass of the qq Jets in the case that the W+W- bosons decay into a Lepton + Neutrino and 2 Quarks. (Semi Leptonic Kinematic Method).

- The datasets used consisted of electron-positron collisions producing W+W- bosons at 180 GeV center of mass energy.
- First, we select leptons from the decay products (muons and electrons).
- Appropriate cuts are made to reduce background.
    - First cut on lepton momentum to remove soft leptons from radiation.
    - Second cut to select specifically a single muon or electron.

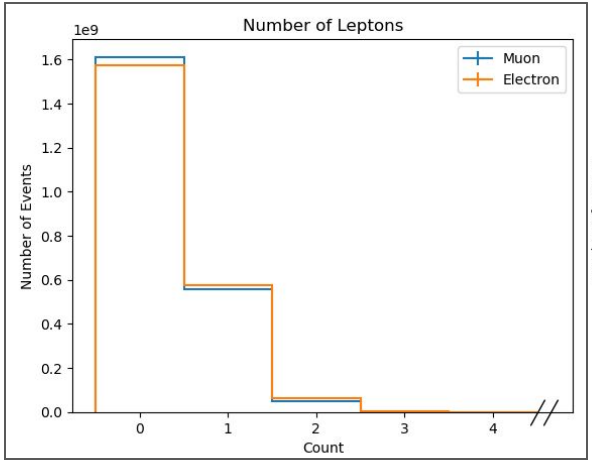
| Datasets: |
|---|
| `yfsww_ee_ww_noBES_ecm180_mw80379_ww2085`<br>`yfsww_ee_ww_noBES_ecm180_mw80479_ww2085`<br>`yfsww_ee_ww_noBES_ecm180_mw80279_ww2085` |

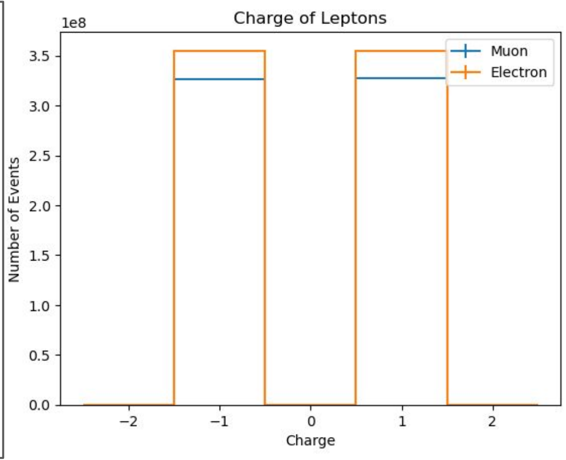
# Procedure cont.

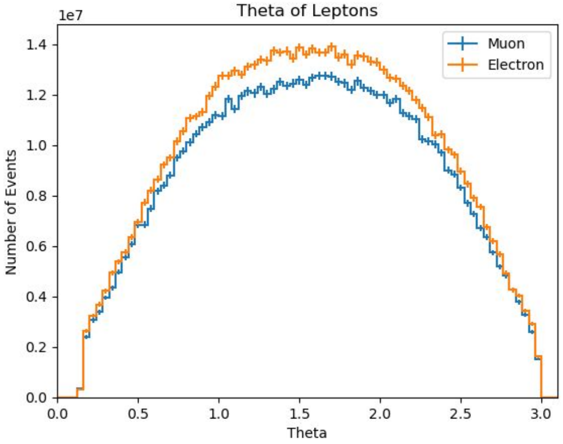


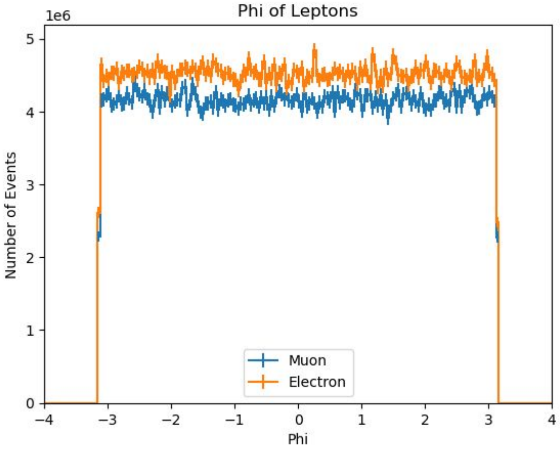

- The neutrino cannot be detected, so after the lepton has been selected and removed, the remaining decay products are clustered into two jets.
- The two jets are then combined into a dijet and a qq invariant mass plot is made.
- This is repeated to create qq invariant mass plots for different W mass assumptions.
- Last, the plots are fitted to Breit-Wigner distributions.

# Data on Selected Leptons



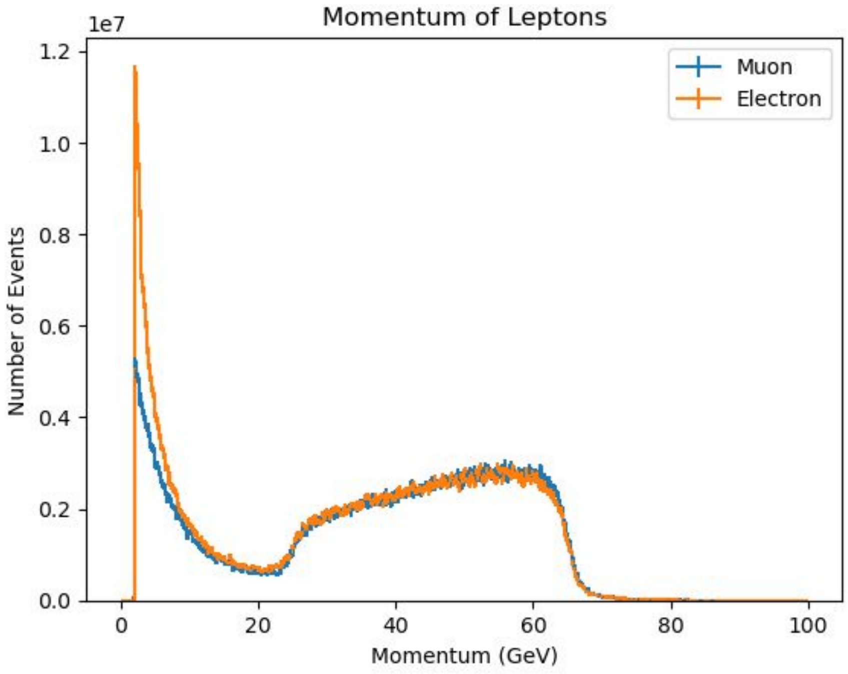



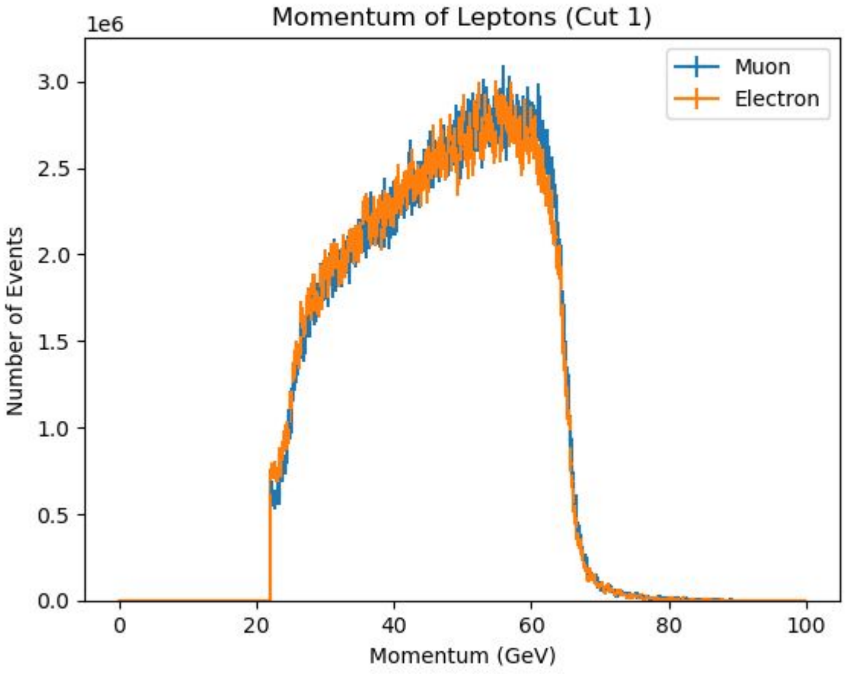



# First Cut

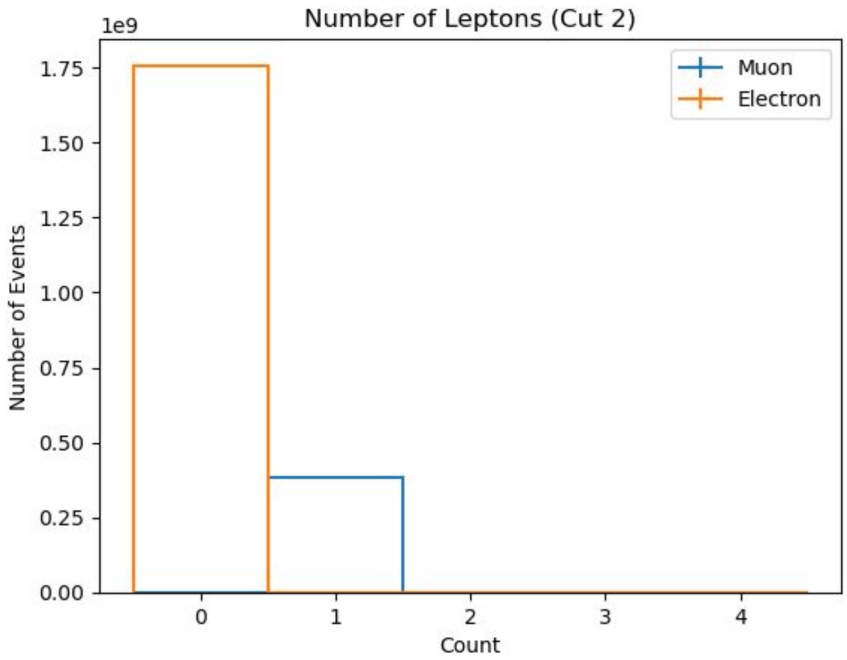
- Selected leptons with > 22 GeV momentum to reduce background.
- First Peak represents soft muons from radiation.

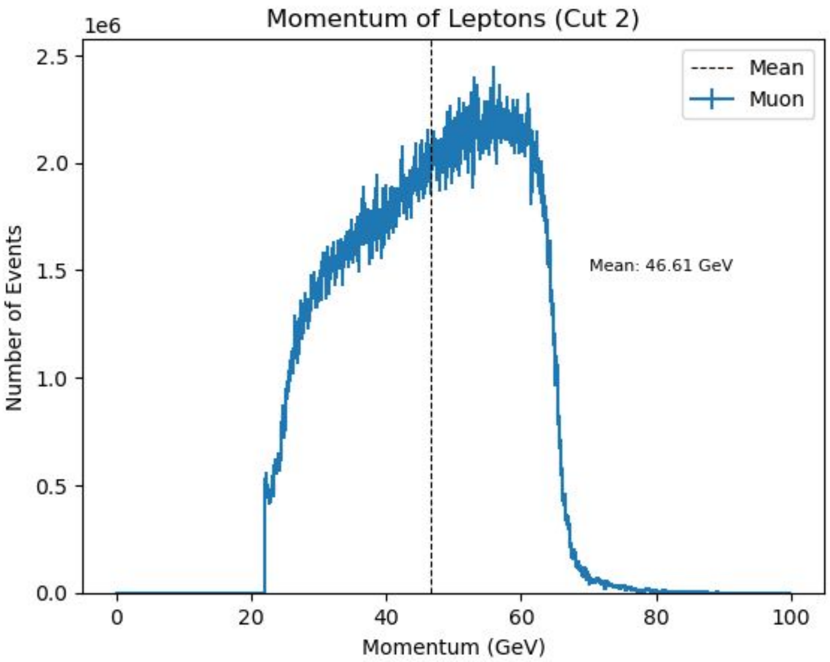


# Second Cut

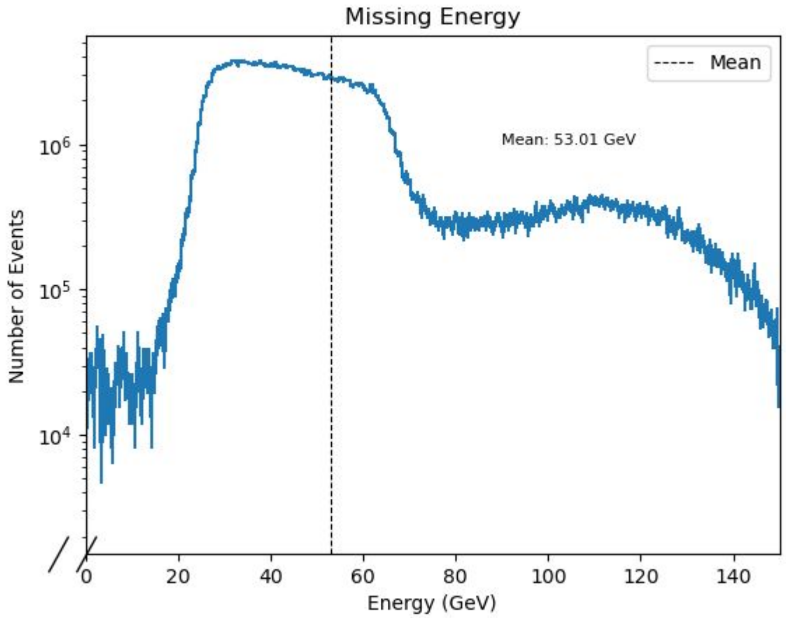
- Selected events with 1 muon and 0 electrons to ensure decay is semi-leptonic.
- The average momentum of remaining leptons is 46.61 GeV.

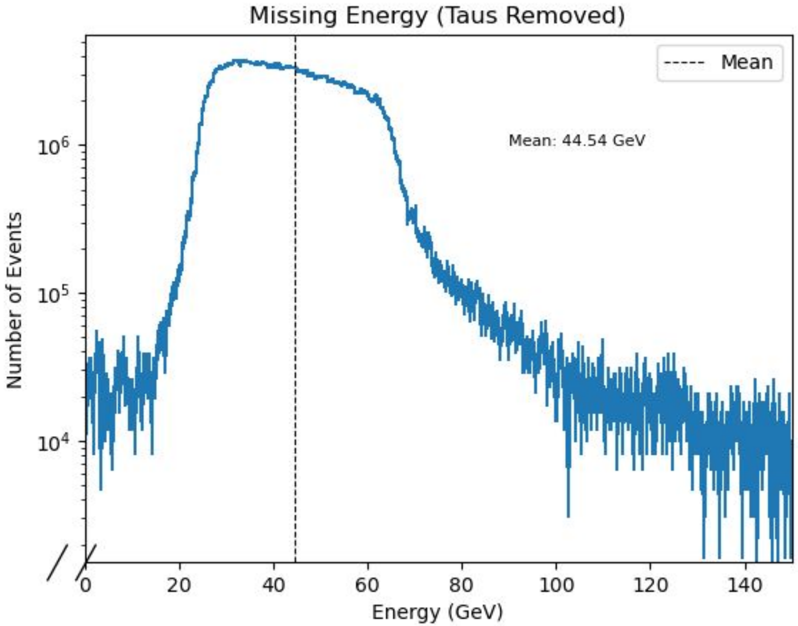


# Missing Energy Graphs

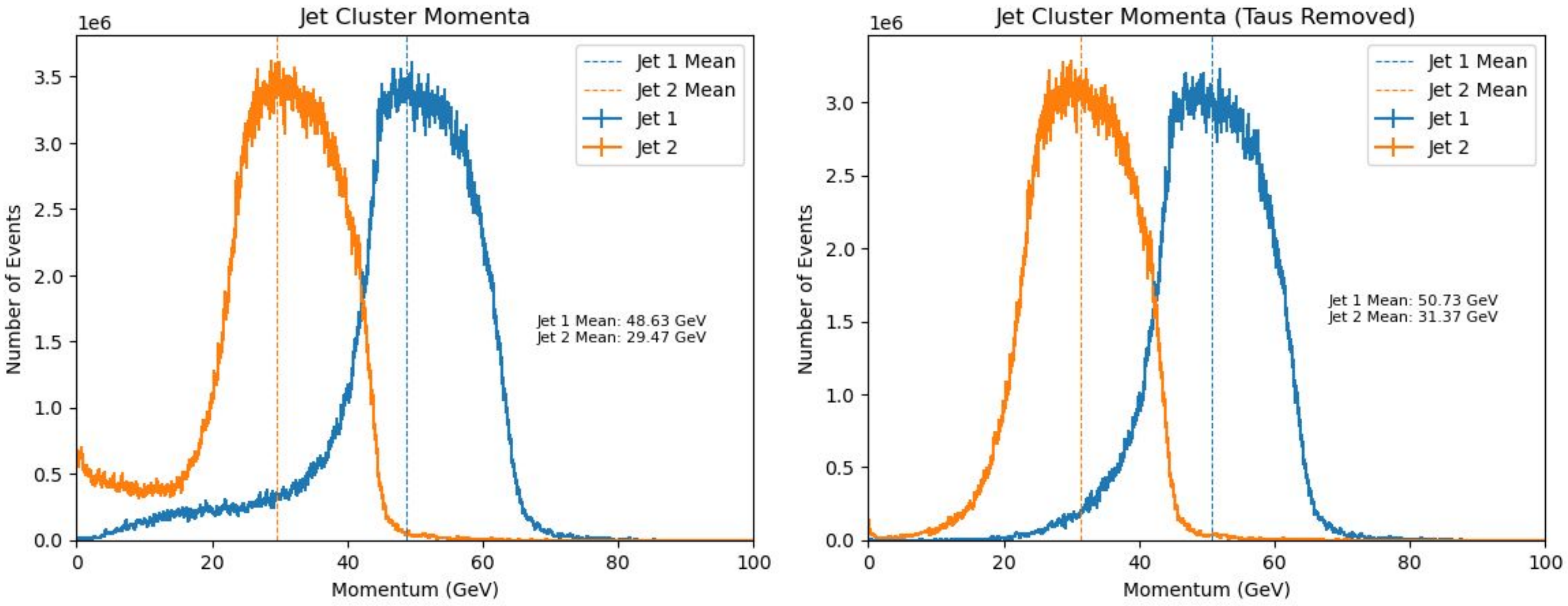
- Missing energy represents the energy of neutrinos since they cannot be detected.
- A hump was discovered in the graph around 80 - 120 GeV.
- Filtering out events which included tau decay products removed this hump.



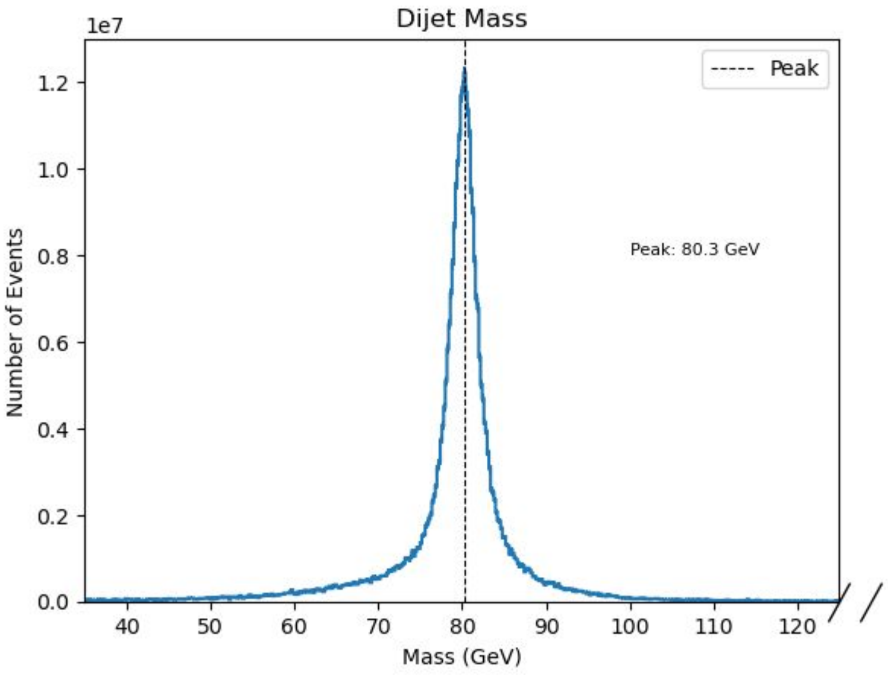



# Jet Momenta

- After lepton removal, the remaining decay products all came from the hadronic decay W boson.
- The remaining decay products were clustered into two jet clusters shown below.

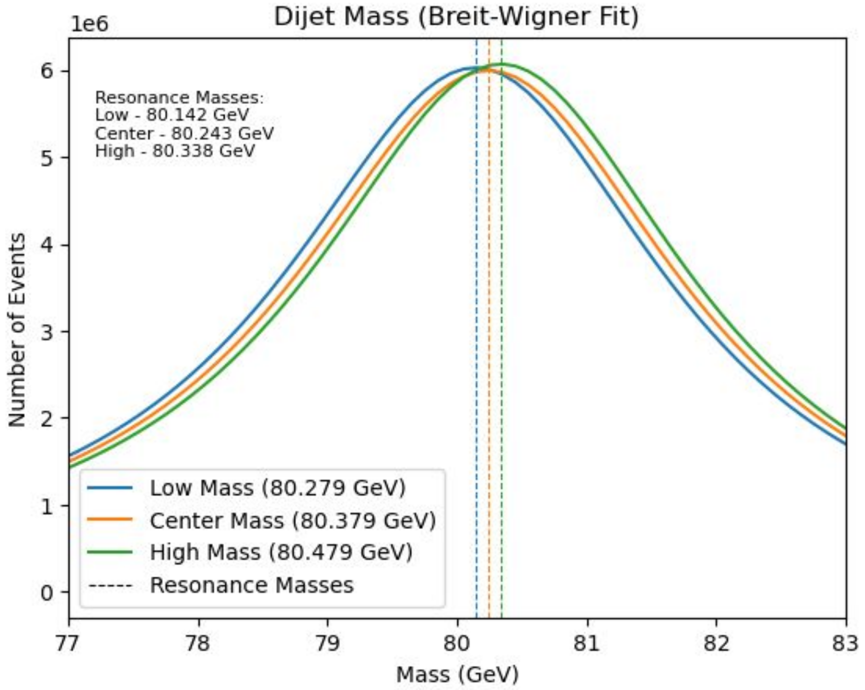


# Dijet Invariant Mass




- When the two jets are combined, the peak mass of the resulting dijet should approximate the mass of the W boson.
- The dijet mass peak occurs at 80.3 GeV, very close to the current value of 80.379 GeV.
- This plot is then made again with samples using different W mass assumptions.

# Breit-Wigner Fit




- The resonance masses of the Breit-Wigner fits represent the peaks of the distributions.
- The resonance masses are 80.142 GeV, 80.243 GeV, and 80.338 GeV.

| | Mass Assumption (GeV) | Resonance Mass (GeV) |
|---|---|---|
| Low Mass | 80.279 | 80.142 |
| Center Mass | 80.379 | 80.243 |
| High Mass | 80.479 | 80.338 |

# Breit-Wigner Fit Parameters

| | Resonance Mass (GeV) | Width (GeV) | Normalization |
|---|---|---|---|
| Low Mass | 80.142 | 3.642 | 34447310.880 |
| Center Mass | 80.243 | 3.662 | 34451518.966 |
| High Mass | 80.338 | 3.622 | 34493597.976 |

## Standard Deviations

| | Resonance Mass (MeV) | Width (MeV) | Normalization |
|---|---|---|---|
| Low Mass | 14.000 | 39.530 | 263990.792 |
| Center Mass | 14.443 | 40.778 | 270846.745 |
| High Mass | 14.174 | 40.022 | 269125.849 |

# Breit-Wigner Fit Observations

- Accounting for standard deviation, the resonance masses are separated by 100 MeV as expected.
- However, all the resonance masses were about 140 MeV lower than the mass assumed in the sample.
- This suggests there is some systematic effect in the measurements or computation causing this discrepancy.

# Conclusions

- The W boson can also decay into Taus which cannot be filtered out in reality but must be accounted for.
- Changing the W mass assumption in the simulation shifts the dijet mass accordingly.
- There is an unknown bias we have shifting the Breit-Wigner fit of the dijet invariant mass around 140 MeV to the left of the assumed masses.
- In the future, we should try to better filter out background events, such as

  Z boson events.