Measuring the Mass of the W Boson through the Semi-Leptonic Kinematic Method

The Annual U.S. FCC Workshop, 2024

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Abstract

The W boson mass, an important parameter in the Standard Model, has a current measured value of 80.379 GeV with an uncertainty of 12 MeV. At FCC-ee, the expected precision could be reduced to 1 MeV level or lower. A Monte-Carlo study is performed using the FCC-ee analysis framework through two decay channels of the W bosons (quarks, which lead to cluster jets, and leptons) at 180 GeV center-of-mass energy to extrapolate the resultant W mass. The W boson mass and uncertainty is extracted from the invariant mass of the hadronic decay products.

Background & Introduction

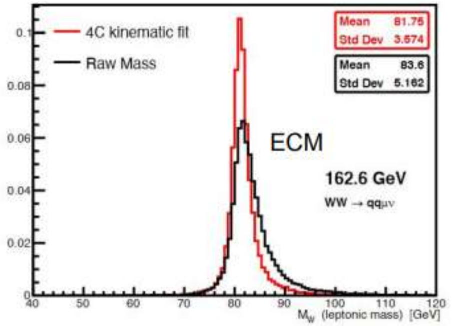
The W Boson:

The W+ and W- bosons are charged gauge bosons that carry the weak force, which is responsible for nuclear β decay (the charged current weak force, specifically). The weak force acts on the weak isospin of particles and therefore, the W bosons interact with all fermions – all quarks and leptons. This weak force couples to and transforms between members of weak isospin doublets; cross generational changes are also permitted, but only in the quark sector; hence why beta decay can occur.

As the W boson is very massive (current measured mass of 80.379 GeV) , compared to the rest of the gauge bosons, when it is exchanged, it is often very virtual – this is part of the reason why the weak force is seemingly weak; it is very short range because highly virtual particles cannot propagate very far.

For the annual U.S. FCC Workshop, we will be working on the measurement of the mass of the W boson using the semi-leptonic kinematic method, in which we look at the decay products of the W boson, which can decay hadronically or leptonically. Since the W boson is charged (W+, W-), we always have 2 W bosons that are produced, for charge conservation. If we assume that one W boson decays leptonically, then we can look at the other W boson, which we must force to decay hadronically. So therefore, we get a lepton and neutrino from one W boson, and two quarks/jets from the other W boson. By plotting the invariant mass of the two jet clusters across all the events, we can infer the mass, by looking at the peak.

The Method

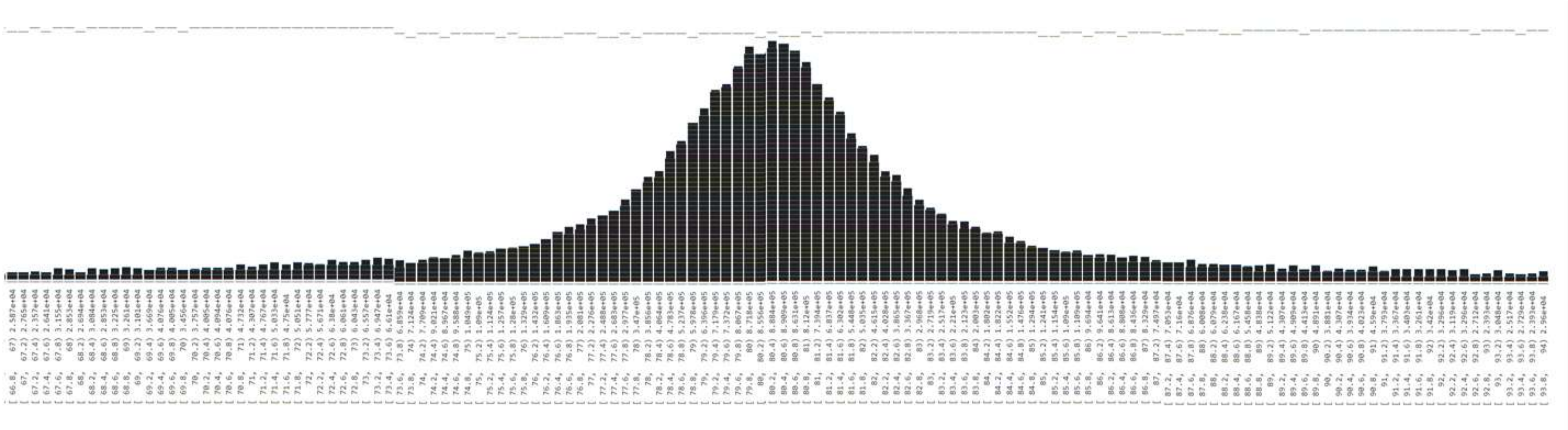


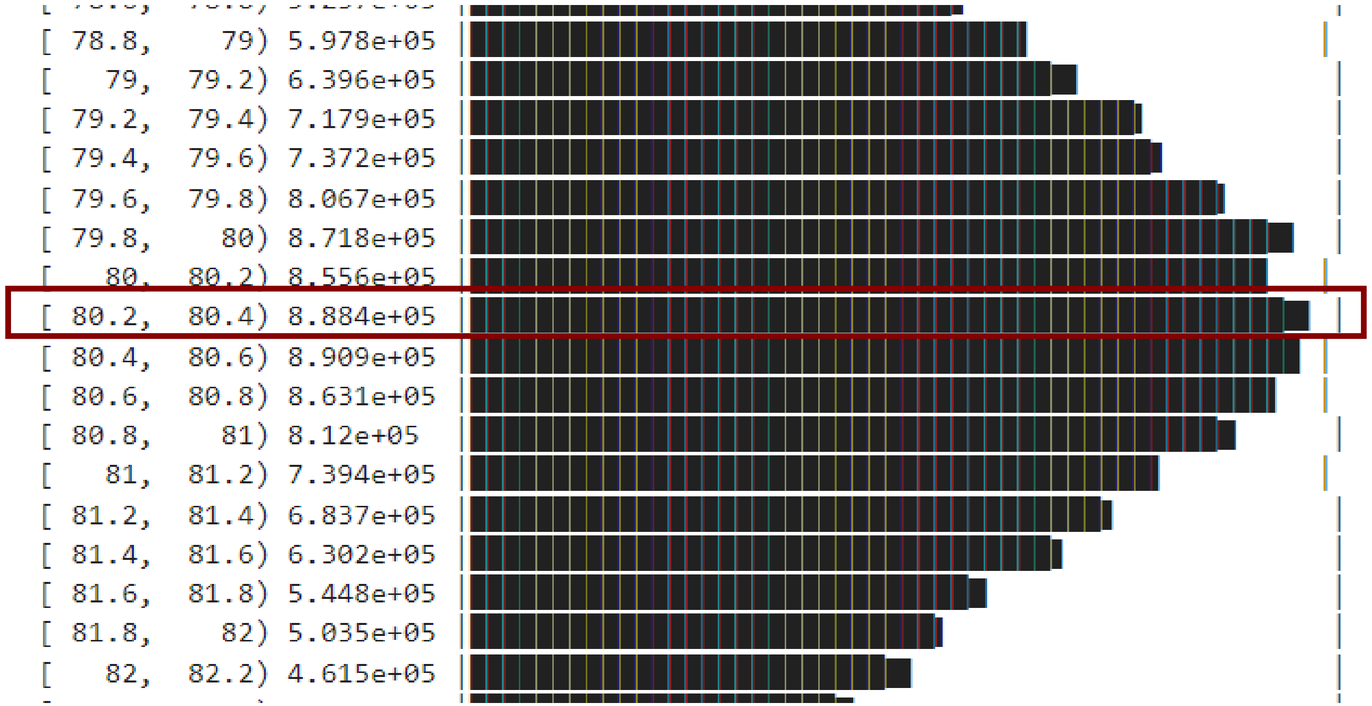
Example of an expected result

The focus was on the sample ‘yfsww_ee_ww_noBES_ecm180_mw80379_ww2085’, which was analysed through a python script, and then processed through submit.

To carry out the analysis, first a lepton was selected; in this case, either the electron or the muon. On the python script, I defined the leptons, and selected those with at least 25GeV. Then the particles from the event went through several cuts; I filtered the leptons to select either the electron, or the muon, since we only want one of the W bosons to decay leptonically, and then the remaining particles from the event were clustered into a pair of jets (after subtracting the selected lepton). From both jets, I formed a 4 vector; a vector including the 3-Dimensional momenta of the particles, and their corresponding energy . The sum of both jets, the 4-vector sum, then lead to the invariant mass of the W boson, since the dijet mass corresponds to the mass of the W boson.

After processing these cuts on submit, the data was stored in a root file, which was then uprooted on a Jupyter Notebook, and plotted on a histogram.





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[ 78.8,     79) 5.978e+05
[   79,   79.2) 6.396e+05
[ 79.2,   79.4) 7.179e+05
[ 79.4,   79.6) 7.372e+05
[ 79.6,   79.8) 8.067e+05
[ 79.8,     80) 8.718e+05
[   80,   80.2) 8.556e+05
[ 80.2,   80.4) 8.884e+05
[ 80.4,   80.6) 8.909e+05
[ 80.6,   80.8) 8.631e+05
[ 80.8,     81) 8.12e+05
[   81,   81.2) 7.394e+05
[ 81.2,   81.4) 6.837e+05
[ 81.4,   81.6) 6.302e+05
[ 81.6,   81.8) 5.448e+05
[ 81.8,     82) 5.035e+05
[   82,   82.2) 4.615e+05
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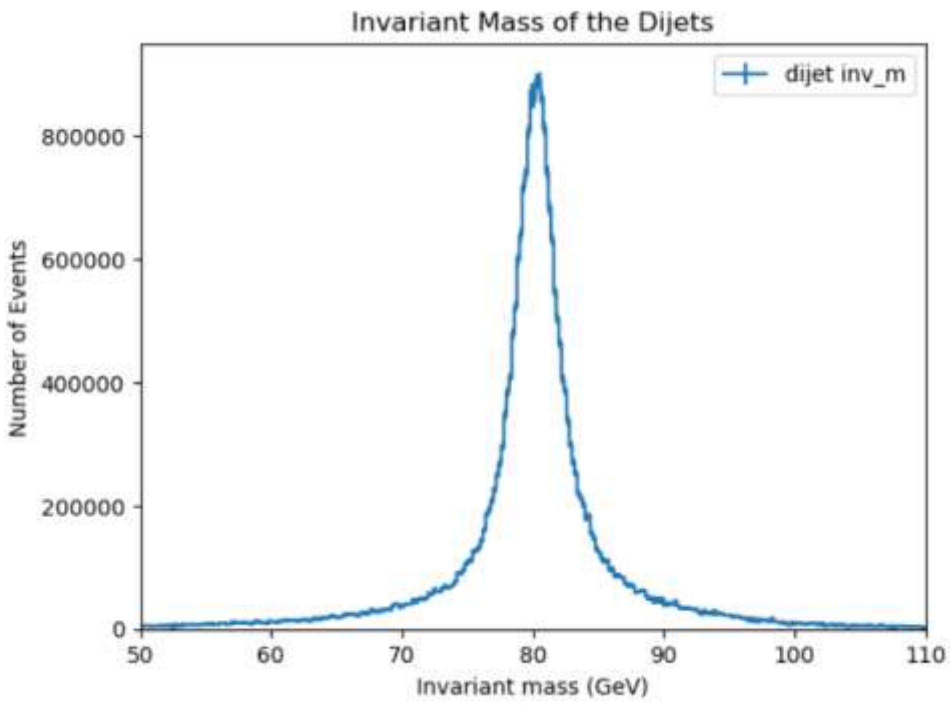
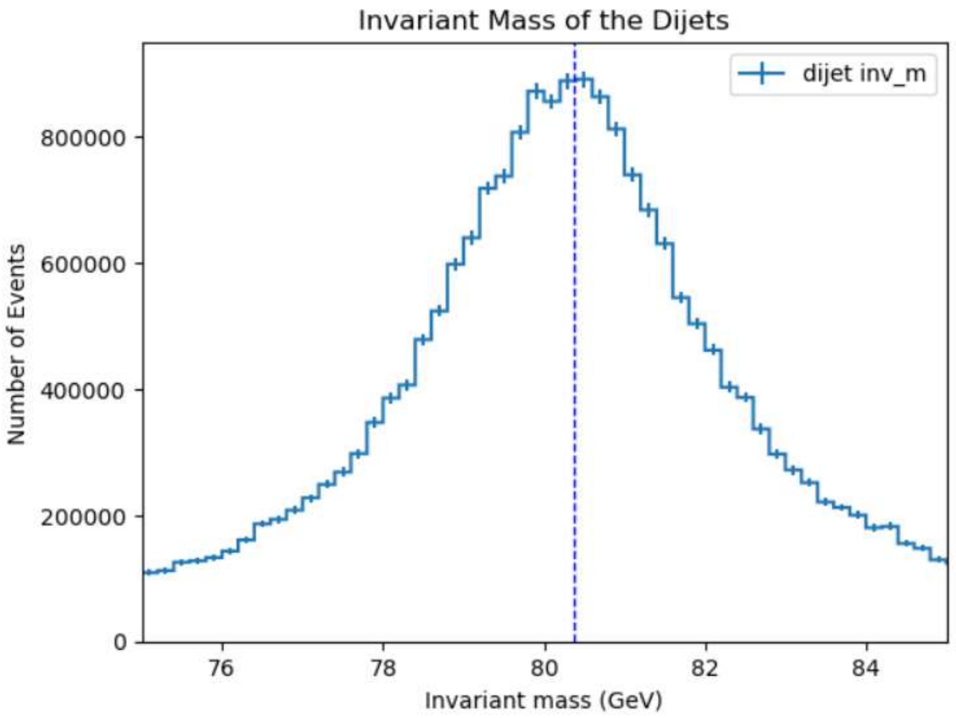
Results

By directly printing the uprooted w mass file onto a Jupyter Notebook, I was able to see a clear mode in the data in the [80.2, 80.4) GeV interval – which is in accordance with the expected mass of the W boson that we had on the sample (80.379 GeV).

Histogram



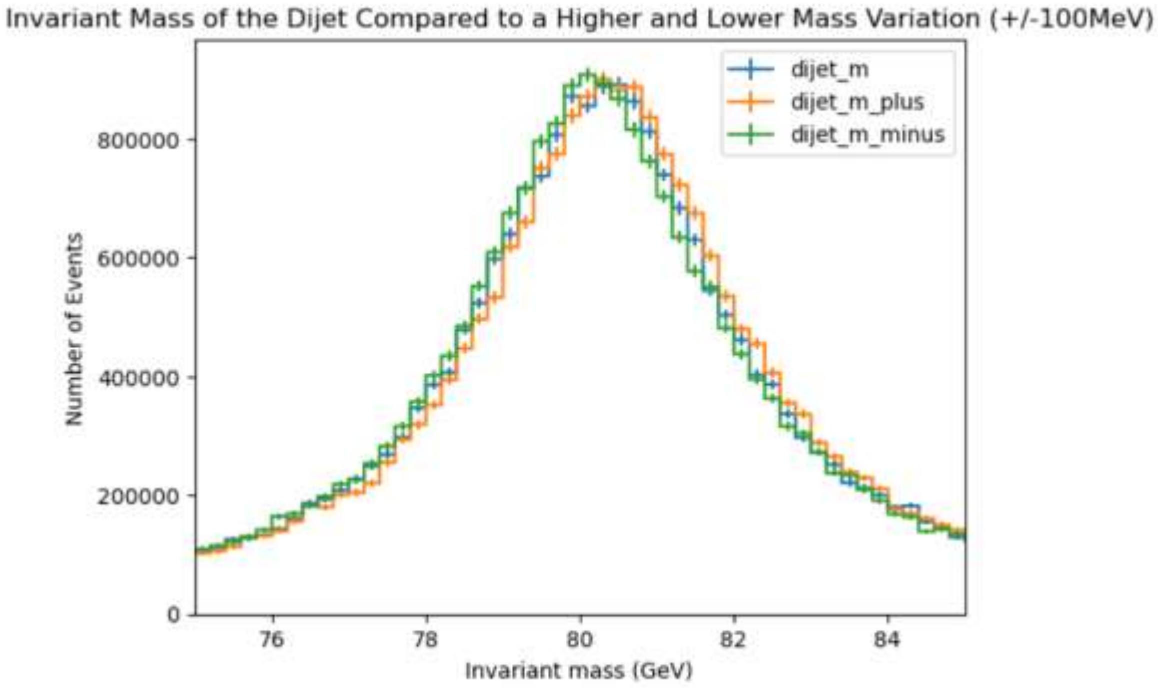


We can see that the events form a very thin bell curve across the interval, with a sharp peak, and zooming in, as expected, the invariant mass of the dijet peaks at the (80.3, 80.4) interval. (For reference, the dashed line goes through 80.379GeV – the expected value of the W boson mass)

Mass Variations

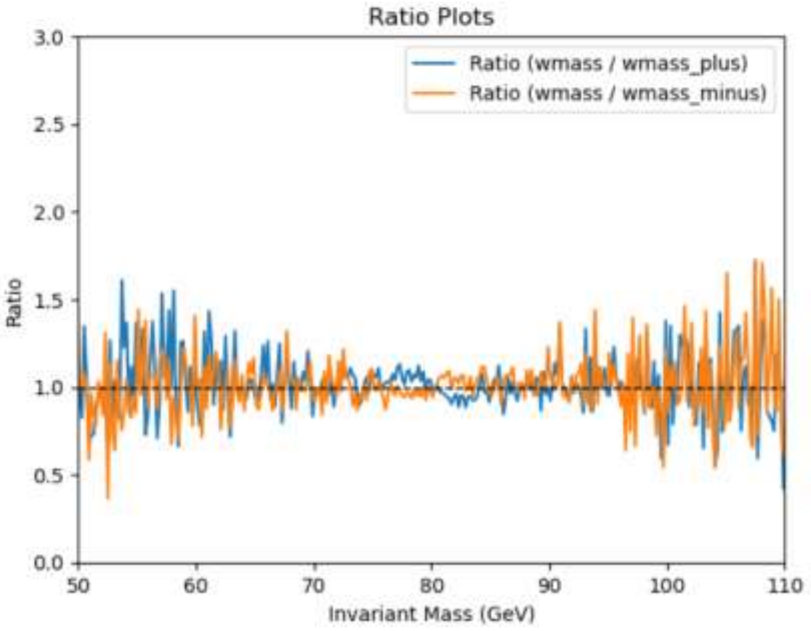
To further investigate the precision of the analysis, samples with an increase, and a decrease of 100MeV were analysed; the sample 'yfsww_ee_ww_noBES_ecm180_mw80479_ww2085' and the sample 'yfsww_ee_ww_noBES_ecm180_mw80279_ww2085'. These samples were identical to the original, but with an assumed mass difference of +/- 100MeV on the Monte Carlo study.

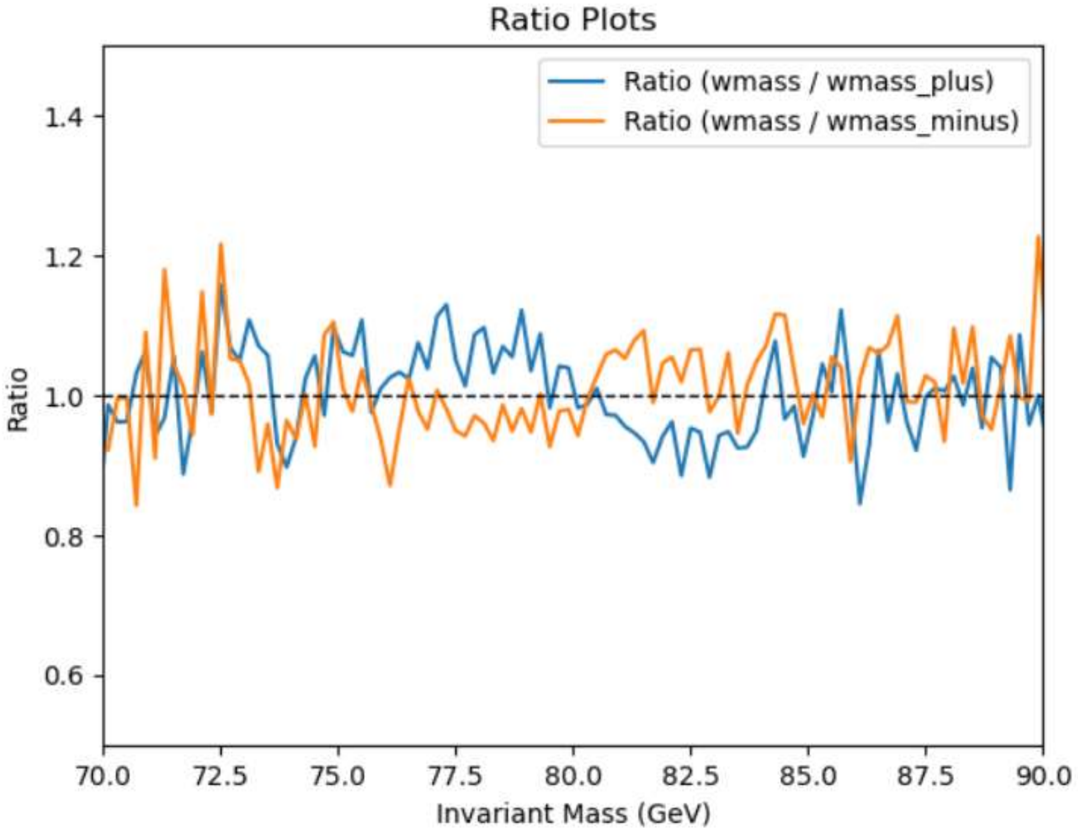
Like the original, they were filtered and analysed through python, and processed through submit, and as expected, there was a shift to the left in the lower mass sample's histogram, and a shift to the right in the higher mass sample's histogram

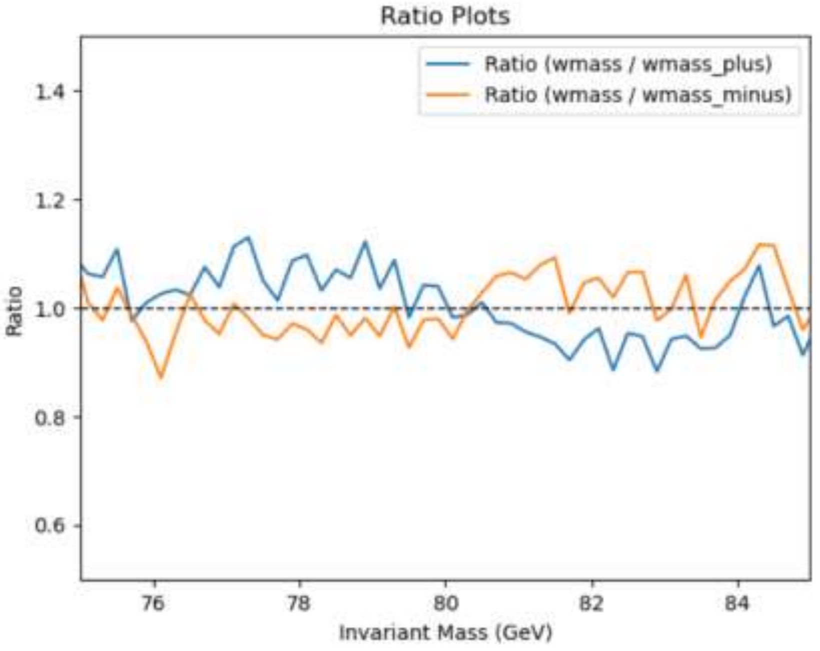


Ratio Plot

To compare the difference in the mass variation histograms, I found the ratios between the original, and +/- 100MeV samples, which we can see on the ratio plots below. Clearly, for very low, and very large invariant masses, there is a lot of disparity, but as we get within the 80 +/- 5 GeV range, a pattern emerges



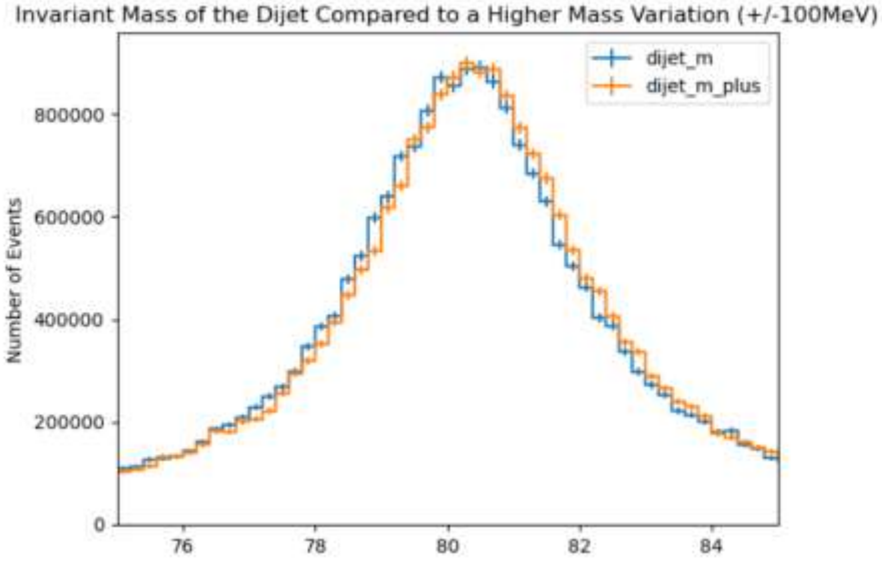


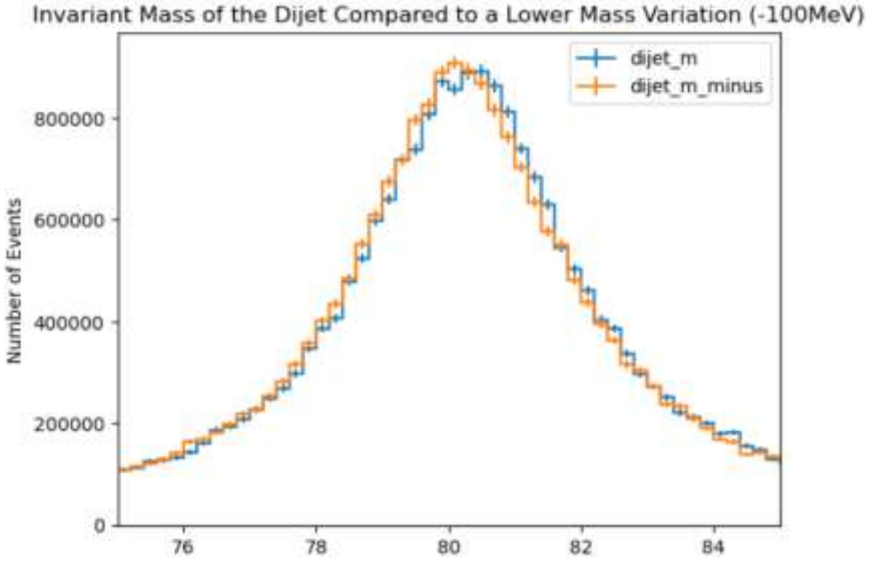


Conclusion

To conclude, we have clearly seen through the Monte-Carlo study, that by looking at the hadronic decay of the W boson, and clustering the particles into a dijet, we can get a very accurate approximation for the mass of the W boson, by looking at where the dijet mass peaks across a large number of events.

Furthermore, we have shown that by varying the mass in the simulation, the sample’s histogram will shift accordingly – to the left with a lower mass, and to the right with a larger mass


Invariant Mass of the Dijet Compared to a Higher Mass Variation (+/-100MeV)


Invariant Mass of the Dijet Compared to a Lower Mass Variation (-100MeV)