Separating the top backgrounds in Higgs self interactions using neural networks

Youn Jun Cho

LMU
LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Background

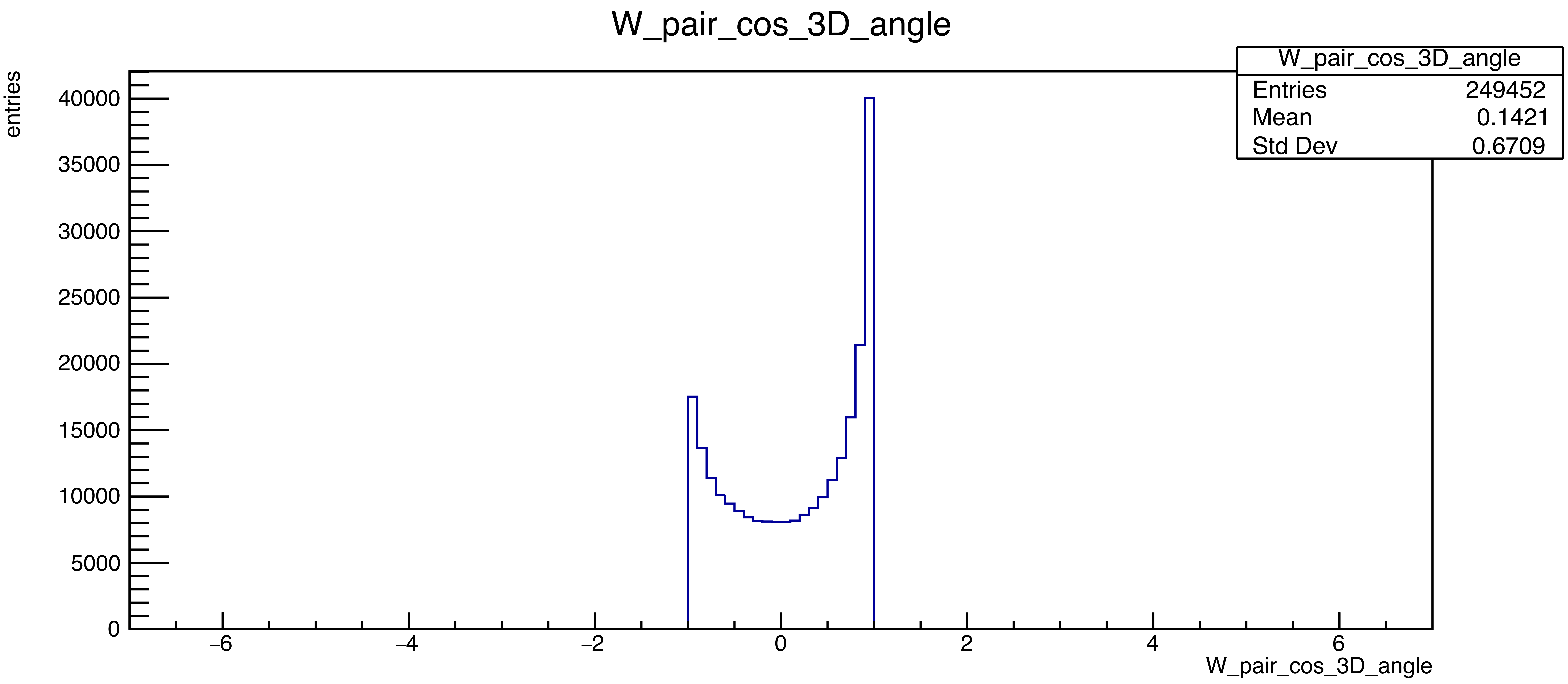
- The top pair decay $t\bar{t} \rightarrow (bW^+)(\bar{b}W^-)$ and the Higgs pair decay $HH \rightarrow (b\bar{b})(W^+W^-)$ have the same daughters
- The two can be mistaken especially when a low mass W boson of mass less than 40 GeV emerges as a top decay product

- Neural networks could easily distinguish kinetically modified top pair end states from those of the Higgs end states
- My goal is to modify data beyond kinematics in the MCatNLO + Herwig generated data in order to see if the Pytorch neural network can still distinguish the two end states

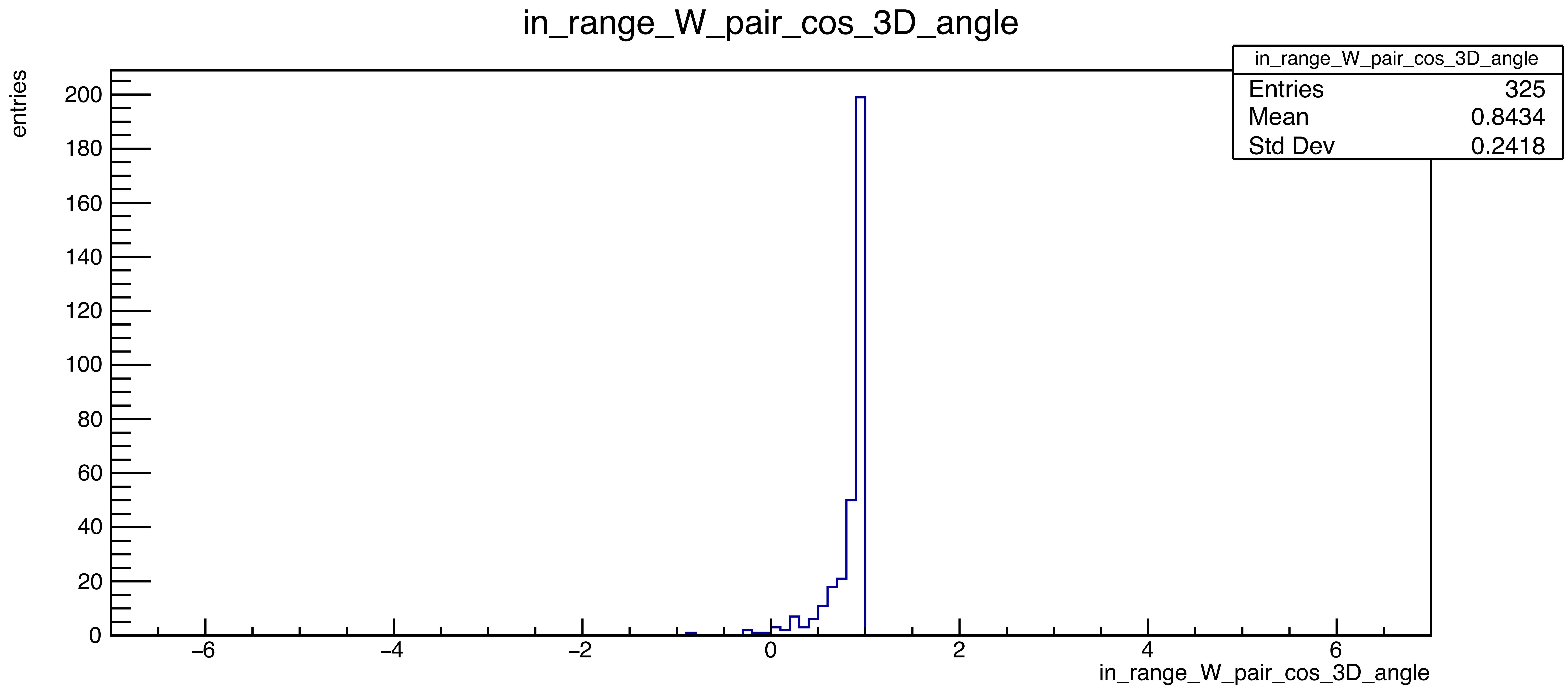
Low Mass W Bosons

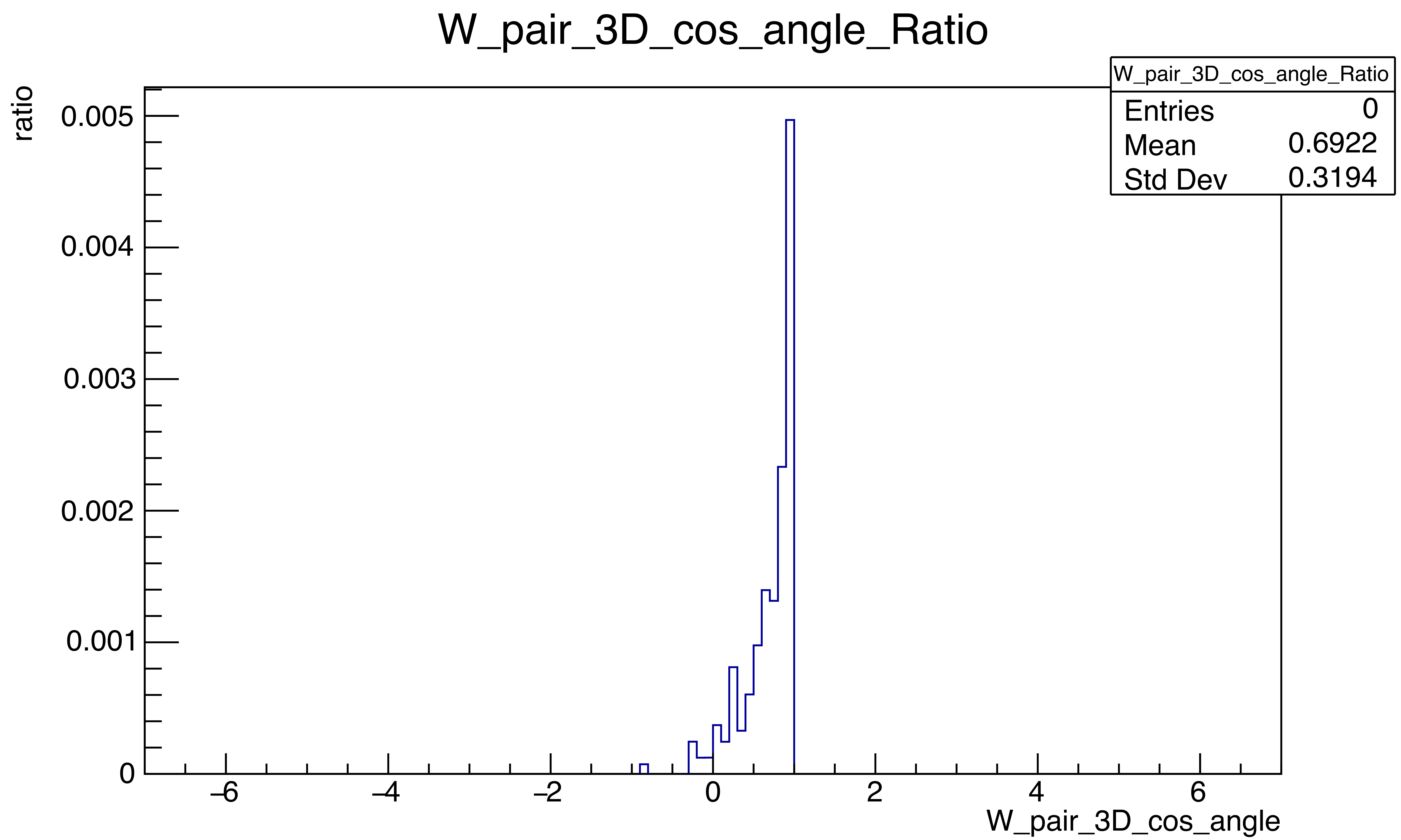
- On average, W bosons with mass less than 40 GeV occurred in only 9 out of 10,000 events in the MCatNLO data, making it difficult to train the neural network
- Acquiring more data through more iterations is impractical due to excessive computation time

- This leads to the practical need to modify the MCatNLO data and see when the low mass W bosons are emitted
- The ratio between cos θ distributions for W jets and for low mass W jets showed that low mass W bosons are 5 times more likely to be emitted when emitted in parallel to its pair



W_pair_cos_3D_angle
W_pair_cos_3D_angle
Entries 249452
Mean 0.1421
Std Dev 0.6709
entries
40000
35000
30000
25000
20000
15000
10000
5000
0
−6
−4
−2
0
2
4
6
W_pair_cos_3D_angle


in_range_W_pair_cos_3D_angle
in_range_W_pair_cos_3D_angle
Entries 325
Mean 0.8434
Std Dev 0.2418
entries
200
180
160
140
120
100
80
60
40
20
0
−6
−4
−2
0
2
4
6
in_range_W_pair_cos_3D_angle



W_pair_3D_cos_angle_Ratio
W_pair_3D_cos_angle_Ratio
Entries 0
Mean 0.6922
Std Dev 0.3194
ratio
0.005
0.004
0.003
0.002
0.001
0
−6
−4
−2
0
2
4
6
W_pair_3D_cos_angle

Two Body Kinematics

- The above coincides with basic results in two body kinematics
- In the rest frame of a particle of mass M decaying into particles of masses m_1 and m_2, the total center of mass energy E can be expressed in the Lorentz invariant form —
- $E^2 = m_1^2 + m_2^2 + 2E_1E_2(1 - \beta_1\beta_2 \cos\theta)^2$, confirming that E would be minimum when $\theta = 0$ (PDG, 49.2)

- Therefore, one rotates and scales the MCatNLO events so that more low mass W bosons can be reconstructed

- The energies and the momenta of the two decay products of a mass M particle can be expressed as:

- $E_1 = \frac{M^2 - m_2^2 + m_1^2}{2M}$ and $|\vec{p}_1| = |\vec{p}_2| = \frac{1}{2M}\sqrt{\Lambda(M^2, m_1^2, m_2^2)}$,

where Λ is the Källen function (PDG, 49.17)

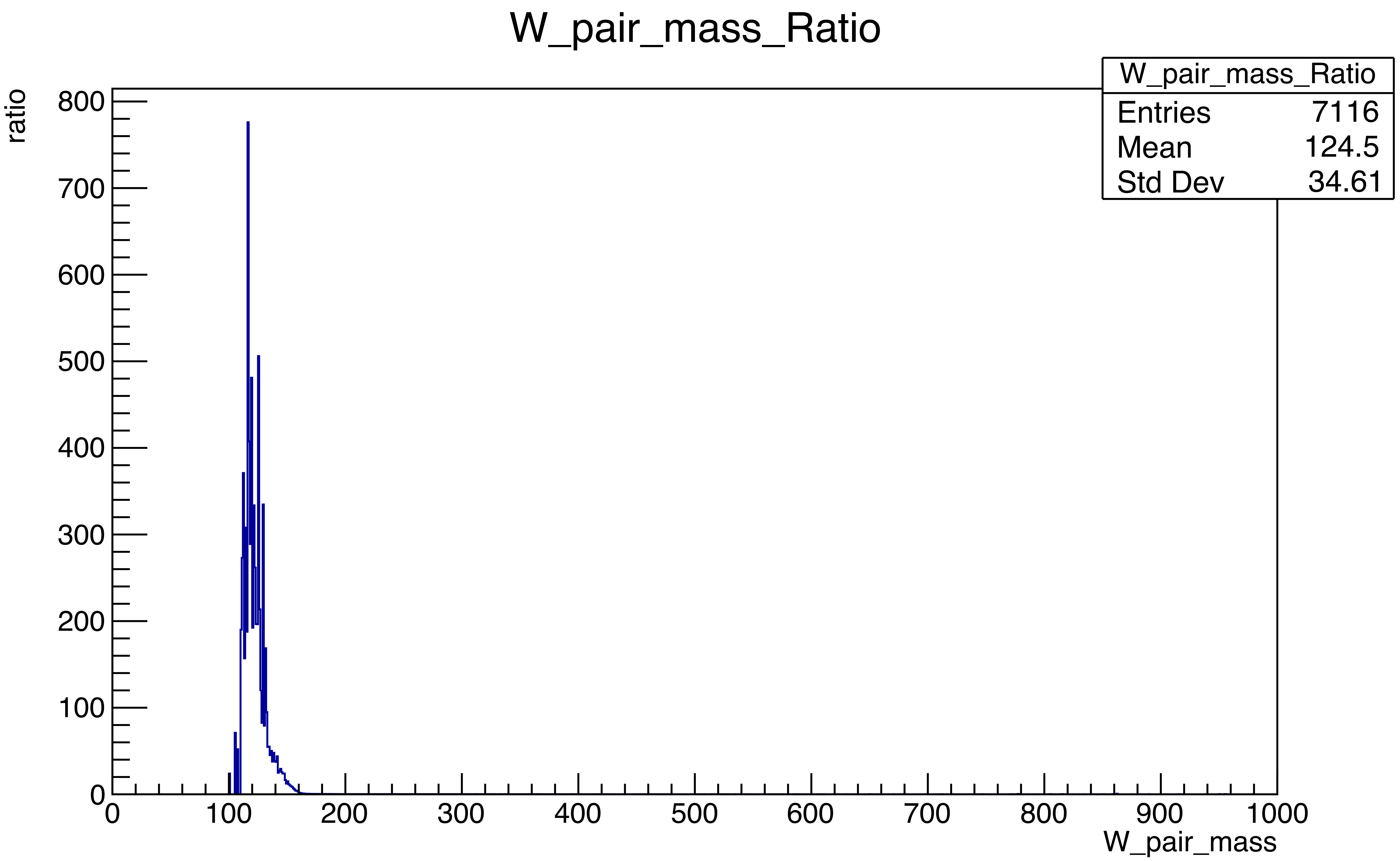
The Rotation Procedure

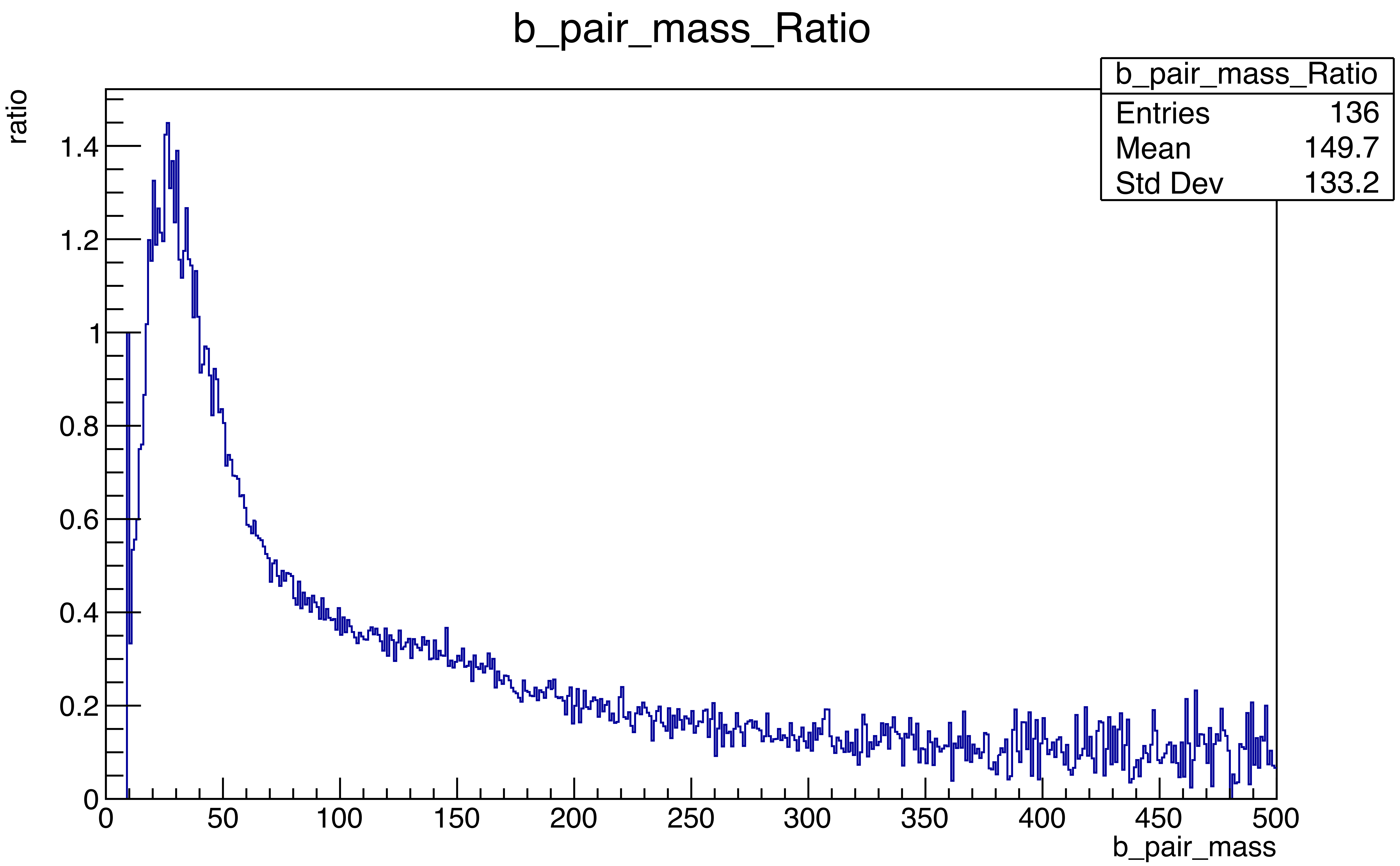
1. Boost the top pair into its rest frame
2. Boost the top decay products into their top parent rest frame
3. Boost the anti-top decay products into their anti-top parent rest frame
4. If a W jet has mass < 80 GeV, then rotate the W jet so that it is parallel to the other W jet

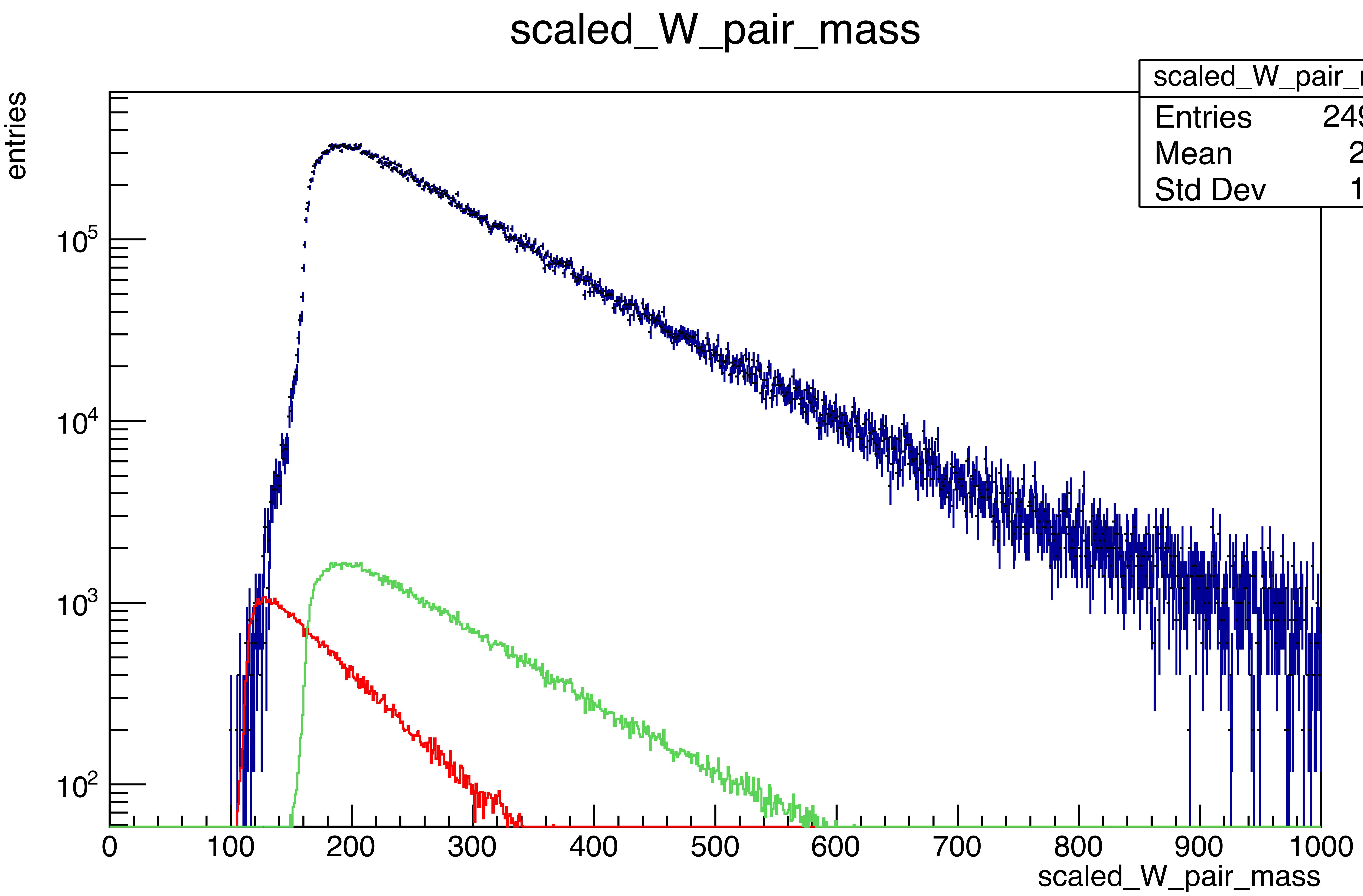
5. Scale that W jet mass along with the bottom jet from the same top parent by a factor of 0.41 using equation (PDG, 49.17)
6. Boost that W jet's decay products into their W parent rest frame and rotate them according to equation (PDG, 49.17)
7. Undo all boosts in reverse order and repeat this procedure on the whole data set

Larger Event Number Histograms

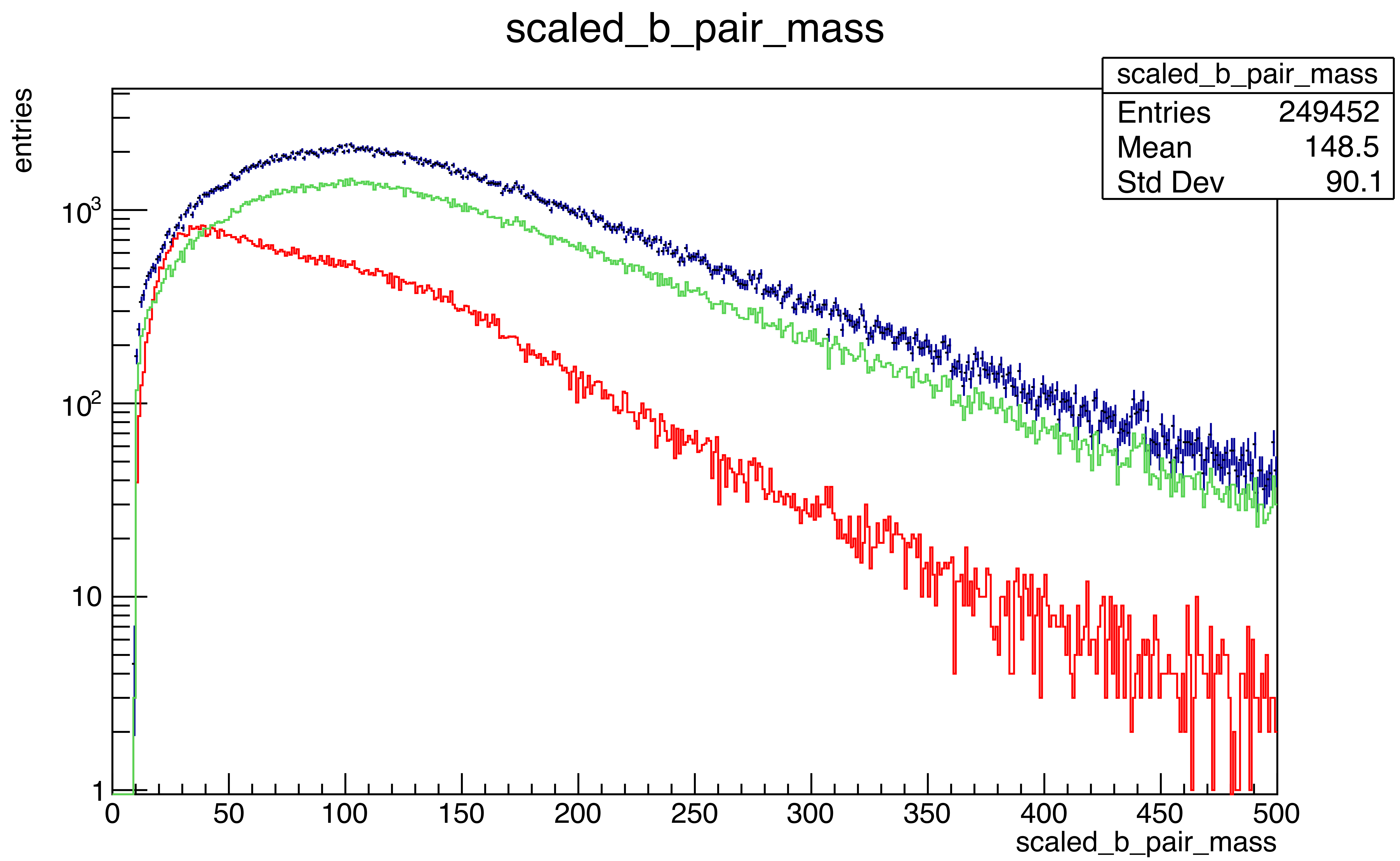
- Compare the new histograms for the pair masses after rotation to the histograms for the pair masses with larger number of events before rotation
- Scale the larger event number histogram before rotation so that it covers the new one up to the point where the W boson pair mass is 125 GeV, using the ratio between the old and the new pair mass histograms
- That requires the old histograms for the W and the b pair masses to be scaled by at least 200 and 1.5 times respectively


W_pair_mass_Ratio
W_pair_mass_Ratio
Entries 7116
Mean 124.5
Std Dev 34.61
ratio
800
700
600
500
400
300
200
100
0
0
100
200
300
400
500
600
700
800
900
1000
W_pair_mass


b_pair_mass_Ratio
b_pair_mass_Ratio
Entries 136
Mean 149.7
Std Dev 133.2
ratio
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
250
300
350
400
450
500
b_pair_mass



scaled_W_pair_mass
scaled_W_pair_mass
Entries 249452
Mean 284.8
Std Dev 117.8
entries
10^5
10^4
10^3
10^2
0
100
200
300
400
500
600
700
800
900
1000
scaled_W_pair_mass


scaled_b_pair_mass
scaled_b_pair_mass
Entries 249452
Mean 148.5
Std Dev 90.1
entries
10^3
10^2
10
1
0
50
100
150
200
250
300
350
400
450
500
scaled_b_pair_mass

- The red histograms represent the pair mass distributions after the rotation procedure
- The green ones represent the ones from before
- The blue ones represent the ones from before the rotation procedure, but with more events

Training the Neural Network

- The input data sets are the events after rotation and the events before rotation but with larger event numbers
- The features to be tested are the pseudorapidity η, the angular distance ΔR, the mass M, and the transverse momenta p_T