Statistical test for VBF DM observables

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Status

- Constructed code to compare the DM VBF models (with the corrected data ratio from Emily and Zara):
  - Ratio plots
  - χ^2 statistical test (With room to adapt for different - more robust - test)
- Compared DM models with the corrected ratios for Mjj
- Produced 2D plots of Mjj vs $\delta\eta$

Reminder of DM models

$$\mathcal{L}_{\mathrm{D5a}} = \frac{1}{\Lambda}\bar{\chi}\chi\left[\frac{Z_\mu Z^\mu}{2} + W^+_\mu W^{-\mu}\right]$$

$$\mathcal{L}_{\mathrm{D5b}} = \frac{1}{\Lambda}\bar{\chi}\gamma^5\chi\left[\frac{Z_\mu Z^\mu}{2} + W^+_\mu W^{-\mu}\right]$$

$$\mathcal{L}_{\mathrm{D5c}} = \frac{g}{2\cos\theta_W\Lambda}\bar{\chi}\sigma^{\mu\nu}\chi\left[\partial_\mu Z_\nu - \partial_\nu Z_\mu\right]$$

$$\mathcal{L}_{\mathrm{D6a}} = \frac{g}{2\cos\theta_W\Lambda^2}\bar{\chi}\gamma^\mu\partial^\nu chi\left[\partial_\mu Z_\nu - \partial_\nu Z_\mu\right]$$

$$\mathcal{L}_{\mathrm{D6b}} = \frac{g}{2\cos\theta_W\Lambda^2}\bar{\chi}\gamma_\mu\partial_\nu chi\epsilon^{\mu\nu\sigma\rho}\left[\partial_\sigma Z_\rho - \partial_\rho Z_\sigma\right]$$

$$\mathcal{L}_{\mathrm{D7a}} = \frac{1}{\Lambda^3}\bar{\chi}\chi W^{i,\mu\nu}W^i_{\mu\nu}$$

$$\mathcal{L}_{\mathrm{D7b}} = \frac{1}{\Lambda^3}\bar{\chi}\gamma^5\chi W^{i,\mu\nu}W^i_{\mu\nu}$$

$$\mathcal{L}_{\mathrm{D7c}} = \frac{1}{\Lambda^3}\bar{\chi}\chi\epsilon^{\mu\nu\rho\sigma}W^i_{\mu\nu}W^i_{\rho\sigma}$$

$$\mathcal{L}_{\mathrm{D7c}} = \frac{1}{\Lambda^3}\bar{\chi}\gamma^5\chi\epsilon^{\mu\nu\rho\sigma}W^i_{\mu\nu}W^i_{\rho\sigma}$$

- DM Mass and Lagrangian term influences the rates and kinematics.
- Can study Higgs 'dark portal' where the interactions are the same as the BSM EFT
- The different dimensions have the EFT constraints:
  - D5c : $\Lambda = 3.3$ TeV
  - D5d : $\Lambda = 6.6$ TeV
  - D6a : $\Lambda = 230$ GeV
  - D6b : $\Lambda = 330$ GeV
  - This has meant that some dimensions would not be seen by any parameters

$(Z\rightarrow \nu\nu)jj/(Z\rightarrow l^+l^-)jj$

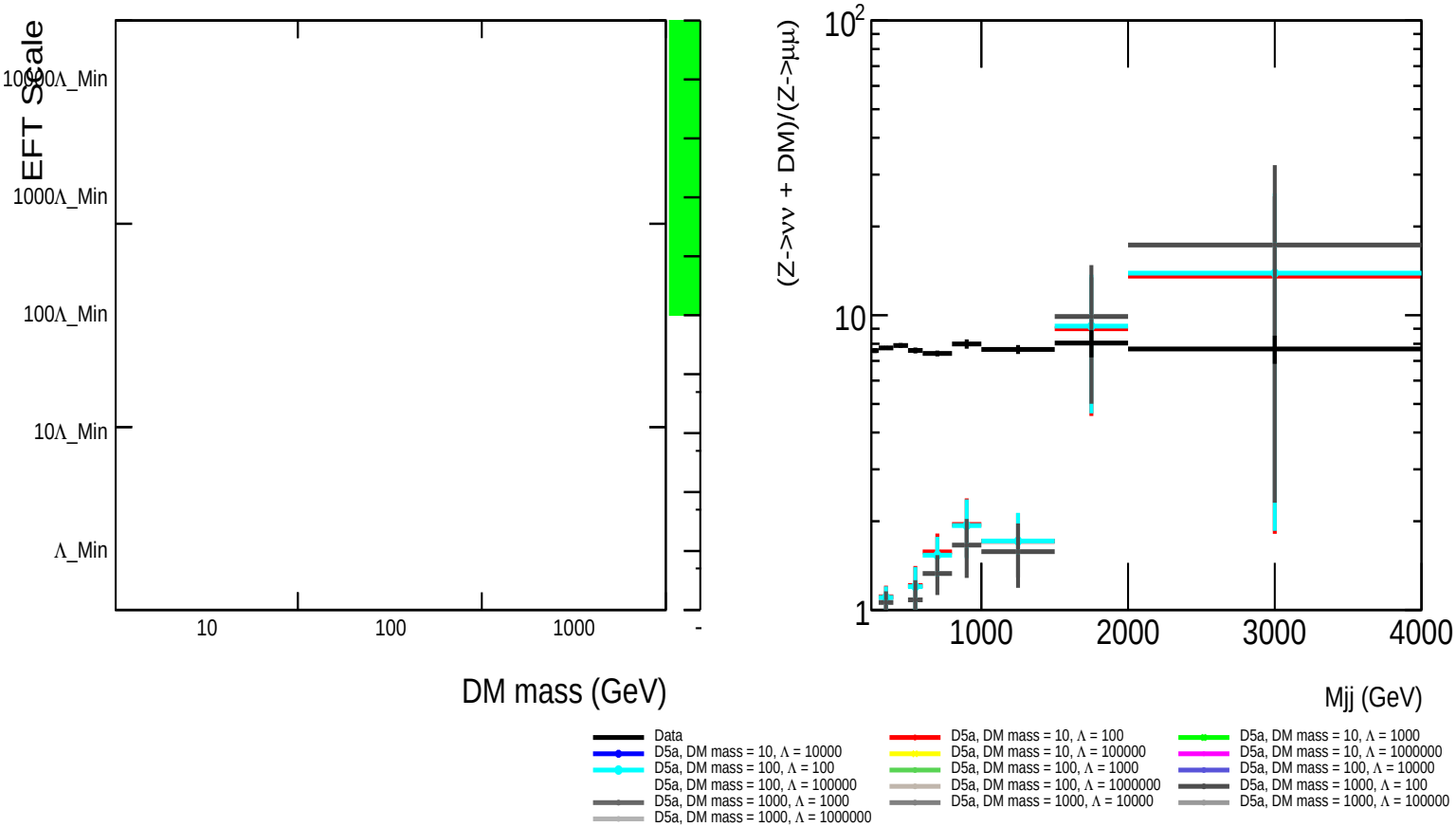
- Ran $(Z\rightarrow \nu\nu)jj$ and $(Z\rightarrow \mu^+\mu^-)jj$ through my Madgraph and Rivet procedure.
- Used this to find the normalised cross-section ratio:

$$[\ (Z\rightarrow \nu\nu)jj + (Z\rightarrow \text{DM DM})jj\ ]/(Z\rightarrow \mu^+\mu^-)jj$$

Cuts for VBFDM Phasespace:

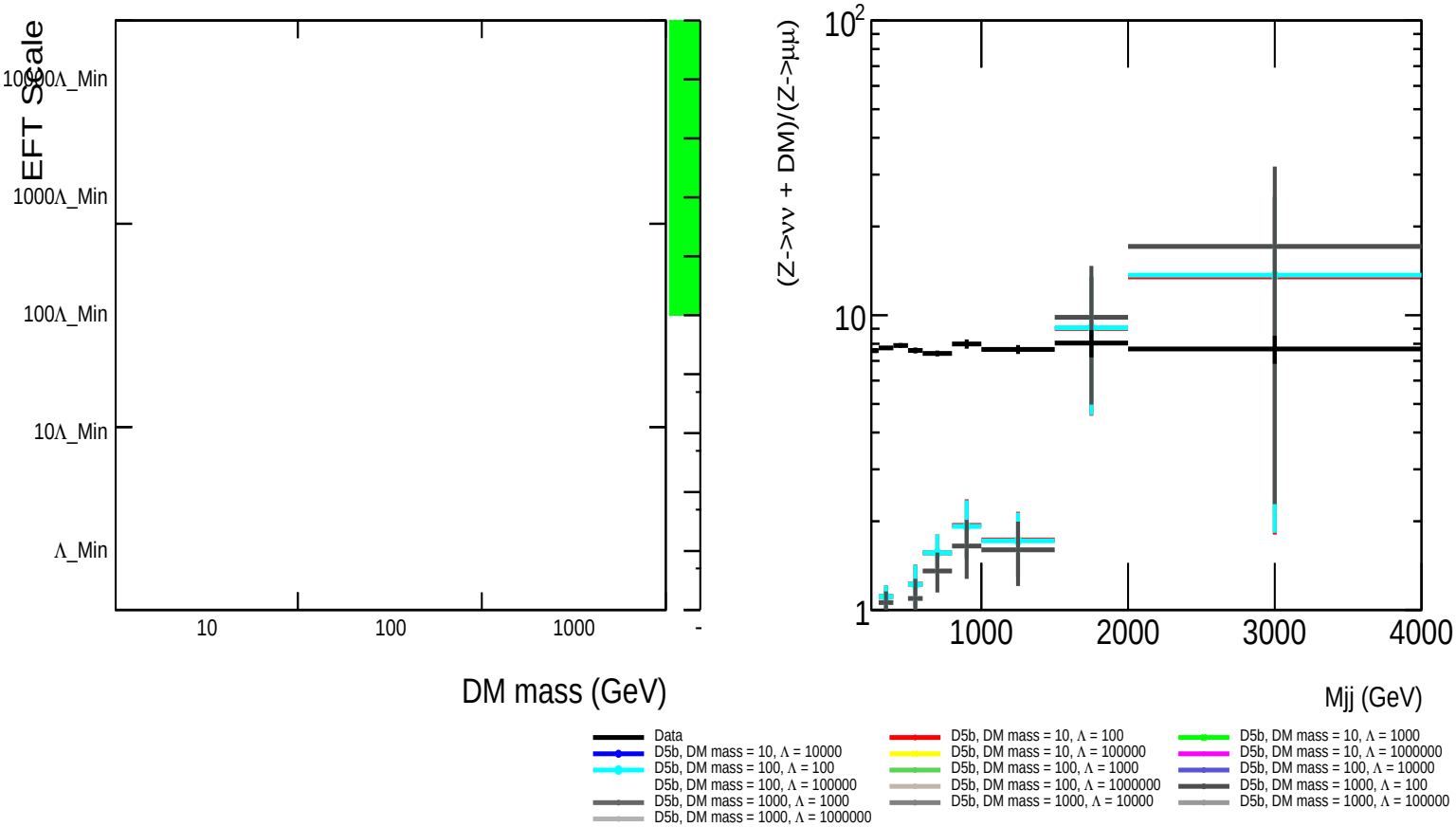
Mjj >250 GeV; Jet1PT >55 GeV; Jet2PT >45 GeV; NumJets $\geq$ 2; abseta <4.4; MET (or dilepton pT) >150 GeV; 66<M(ll)<116 GeV.

Comparison: D5a : Mjj : $\Lambda_{Min} = 100$GeV



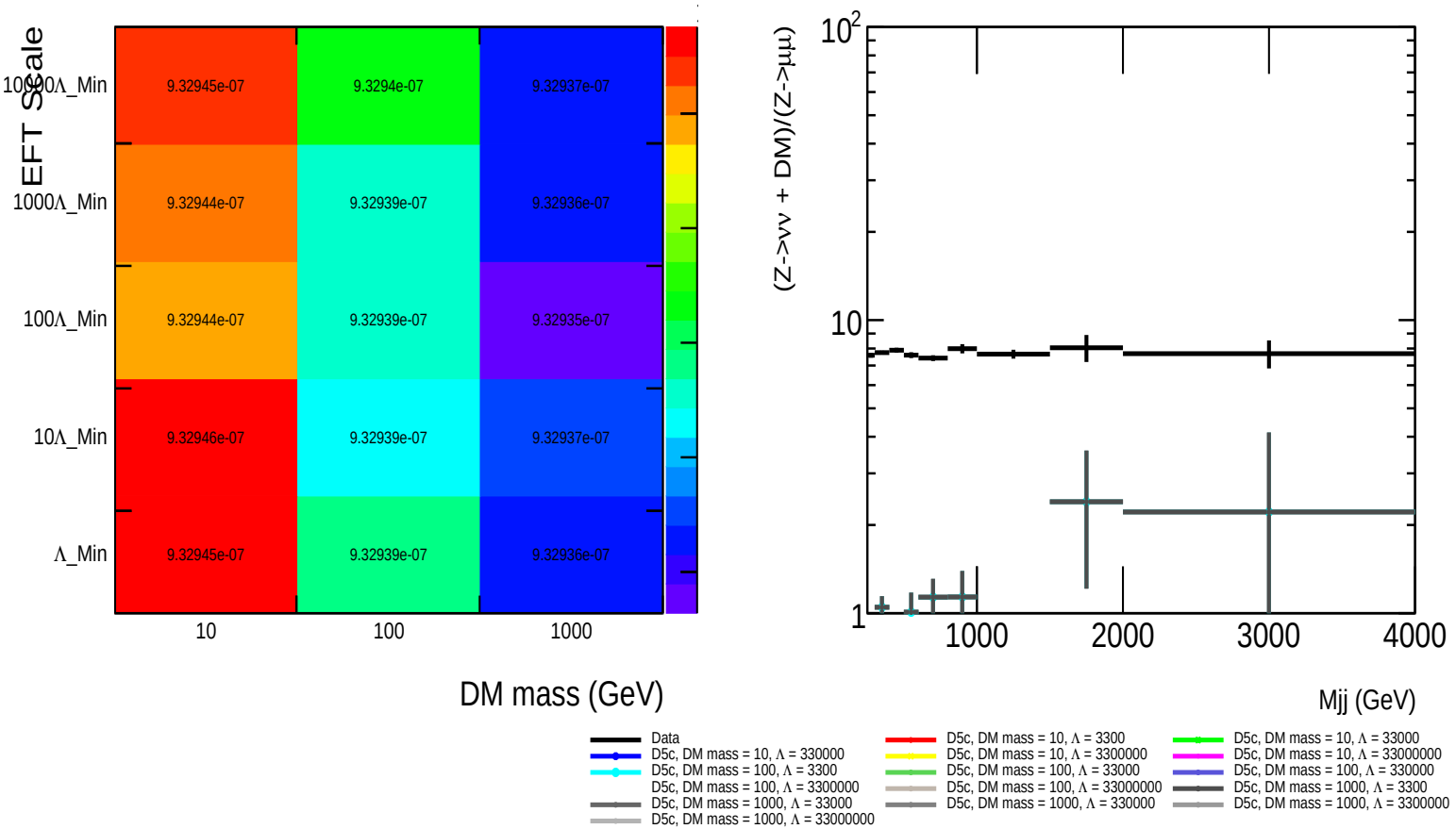
- The bins in the 2D histogram here haven't filled as the χ^2 p-value is so low.

Comparison: D5b : Mjj : $\Lambda_{Min} = 100$GeV



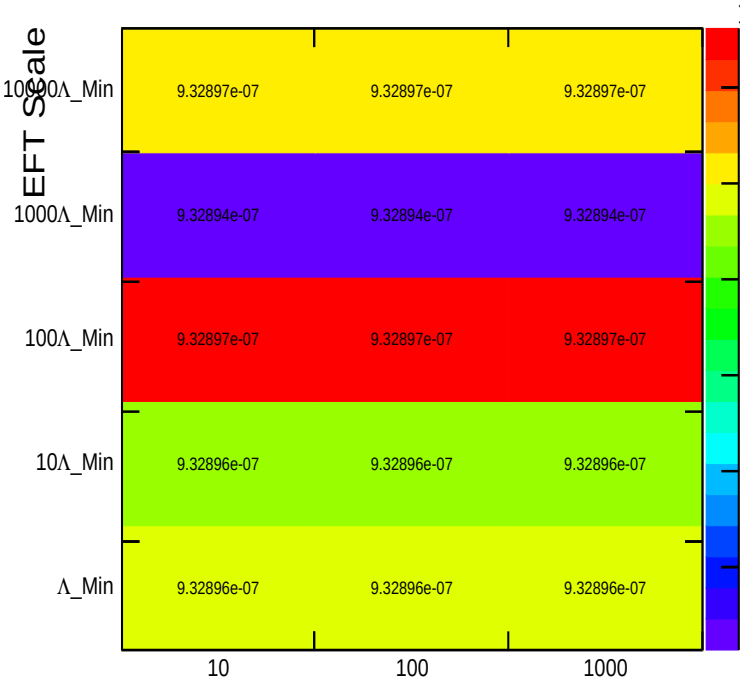
- The bins in the 2D histogram here haven't filled as the χ^2 p-value is so low.

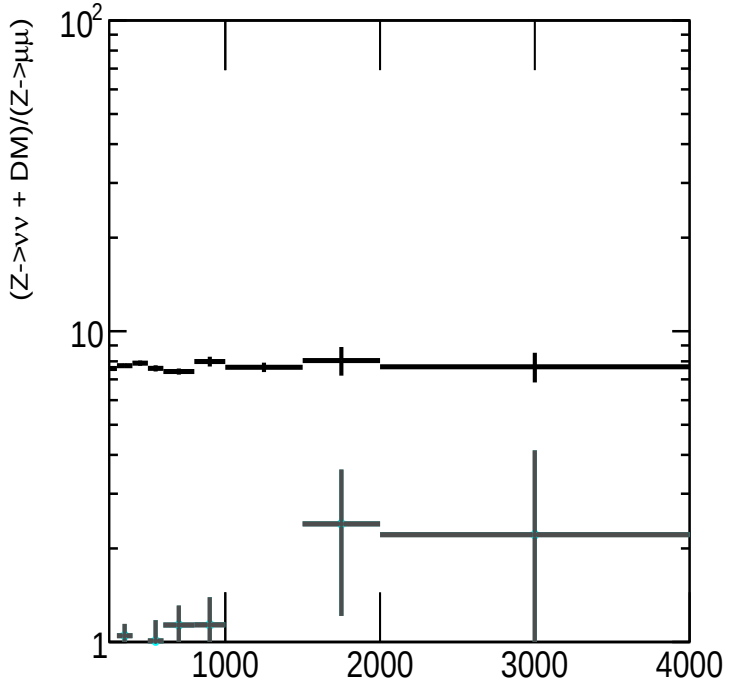
Comparison: D5c : Mjj : $\Lambda_{Min} = 3.3$TeV

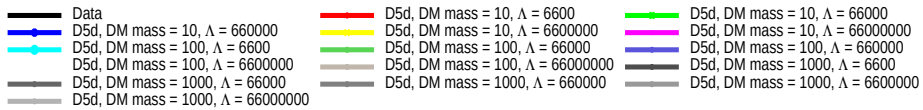


- The bins have filled here as the shape is closer to the data, however, the p-value is still very small.
- The bins seem to fill the same regardless of the EFT scale - Might be a bug in my code and I'm looking into fixing it at the moment.

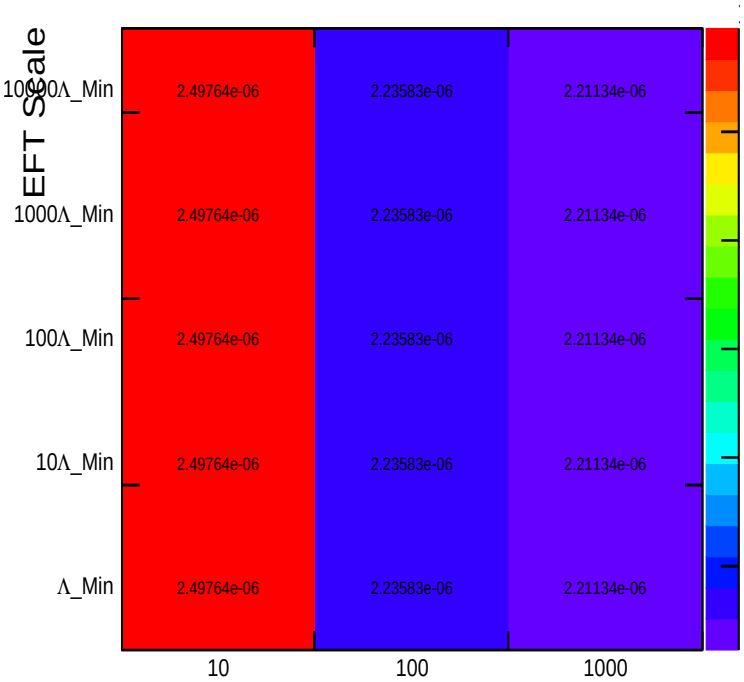
Comparison: D5d : Mjj : $\Lambda_{Min} = 6.6$TeV

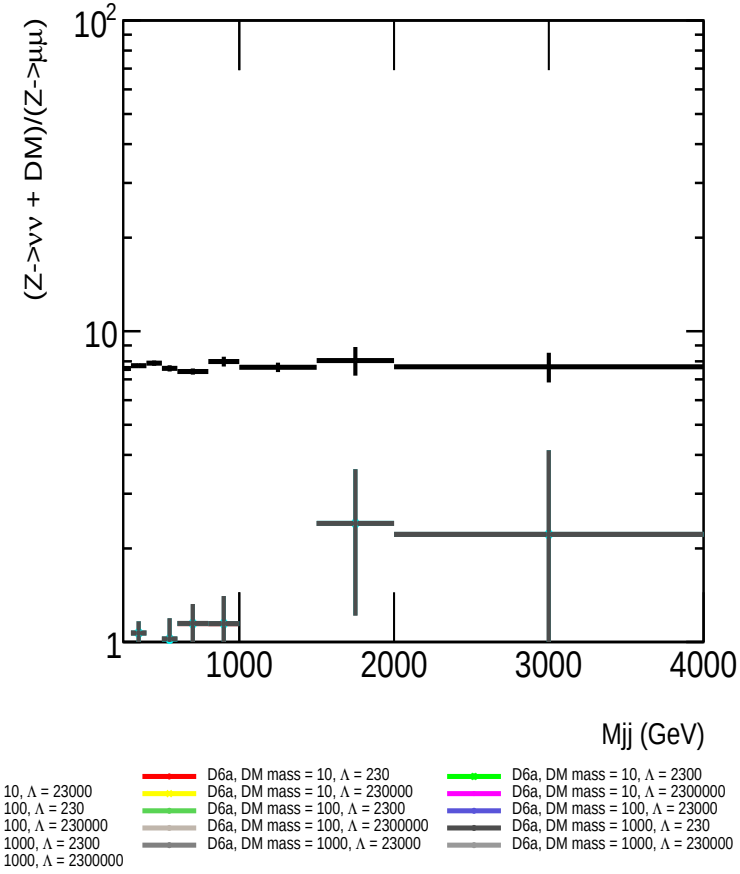




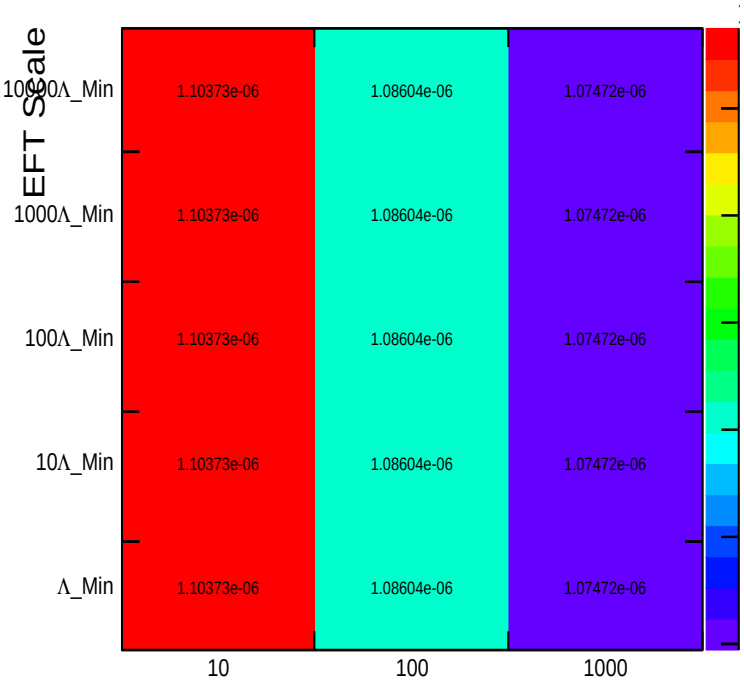


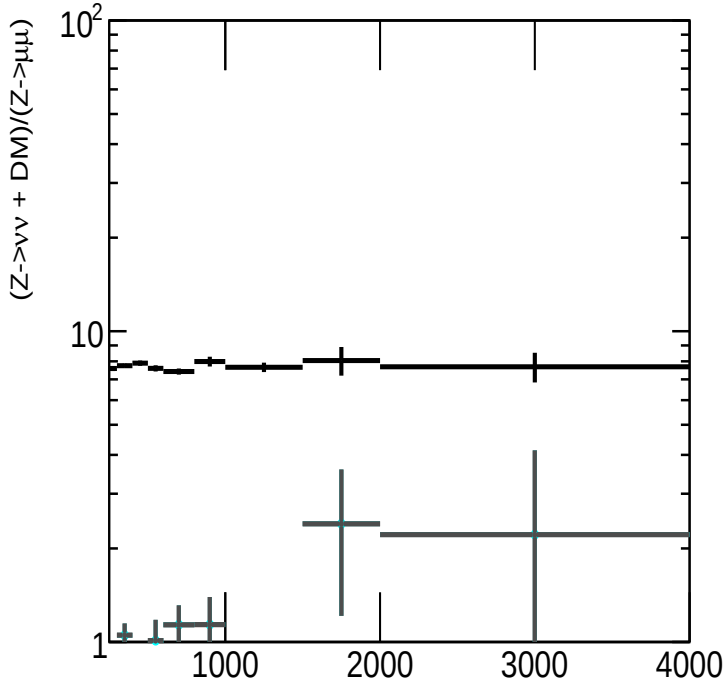
Comparison: D6a : Mjj : $\Lambda_{Min} = 230$GeV





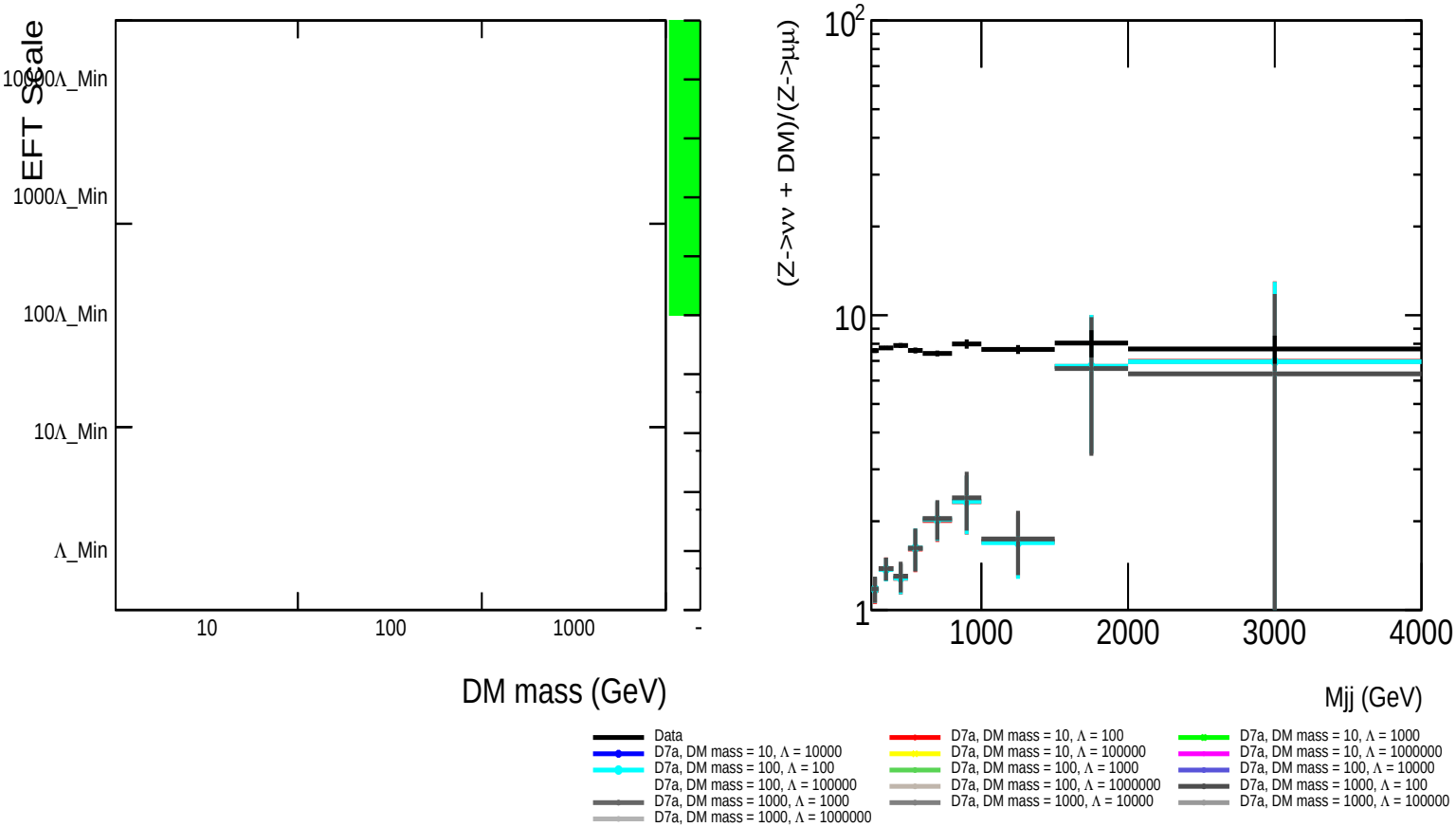
Comparison: D6b : Mjj : $\Lambda_{Min} = 330$GeV





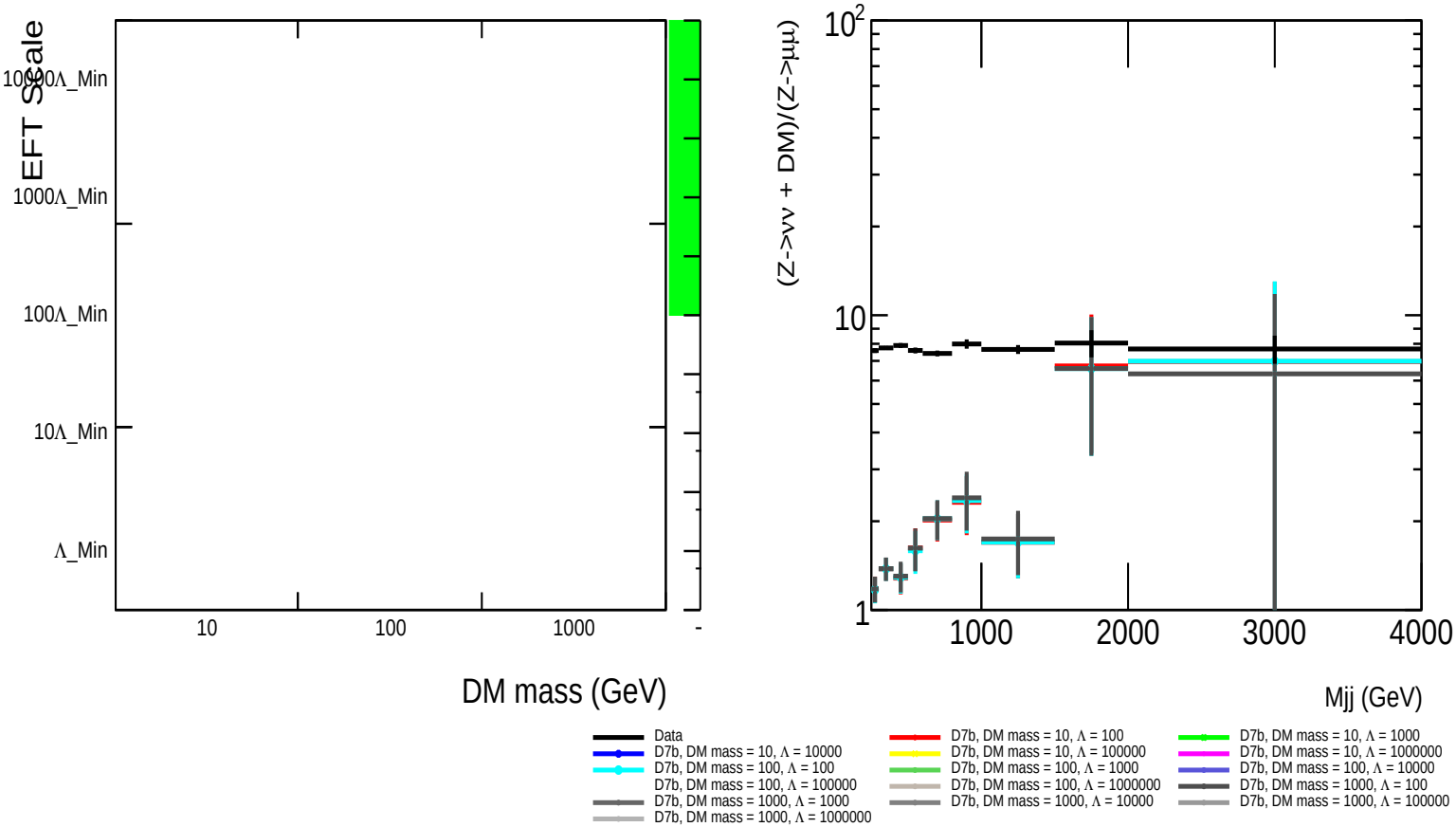
Data
D6b, DM mass = 10, Λ = 33000
D6b, DM mass = 100, Λ = 330
D6b, DM mass = 100, Λ = 330000
D6b, DM mass = 1000, Λ = 3300
D6b, DM mass = 1000, Λ = 3300000
D6b, DM mass = 10, Λ = 330
D6b, DM mass = 10, Λ = 330000
D6b, DM mass = 100, Λ = 3300
D6b, DM mass = 100, Λ = 3300000
D6b, DM mass = 1000, Λ = 33000
D6b, DM mass = 10, Λ = 3300
D6b, DM mass = 10, Λ = 3300000
D6b, DM mass = 100, Λ = 33000
D6b, DM mass = 1000, Λ = 330
D6b, DM mass = 1000, Λ = 330000

Comparison: D7a : Mjj : $\Lambda_{Min} = 100$GeV



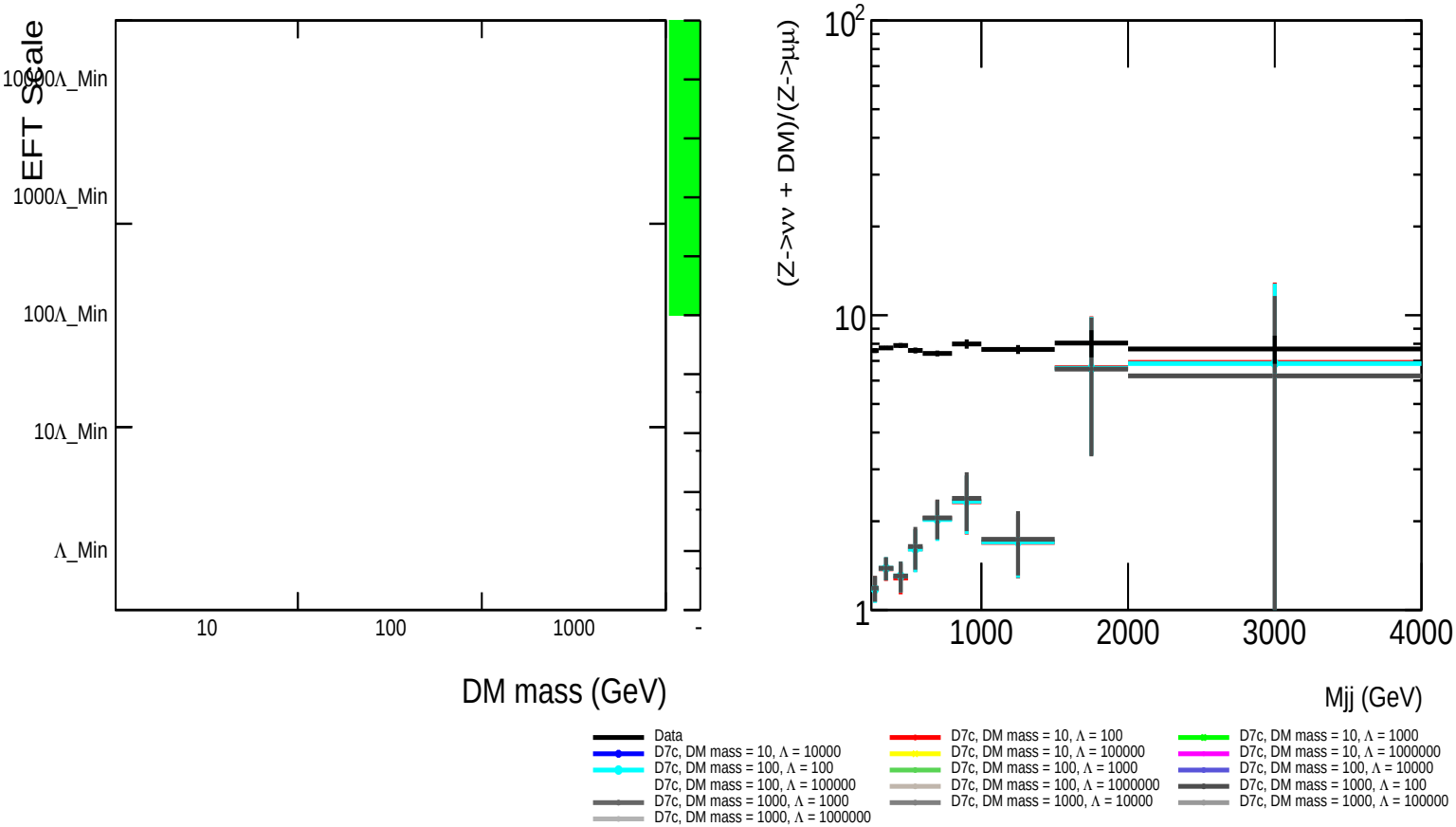
- The bins in the 2D histogram here haven't filled as the χ^2 p-value is so low.

Comparison: D7b : Mjj : $\Lambda_{Min} = 100$GeV



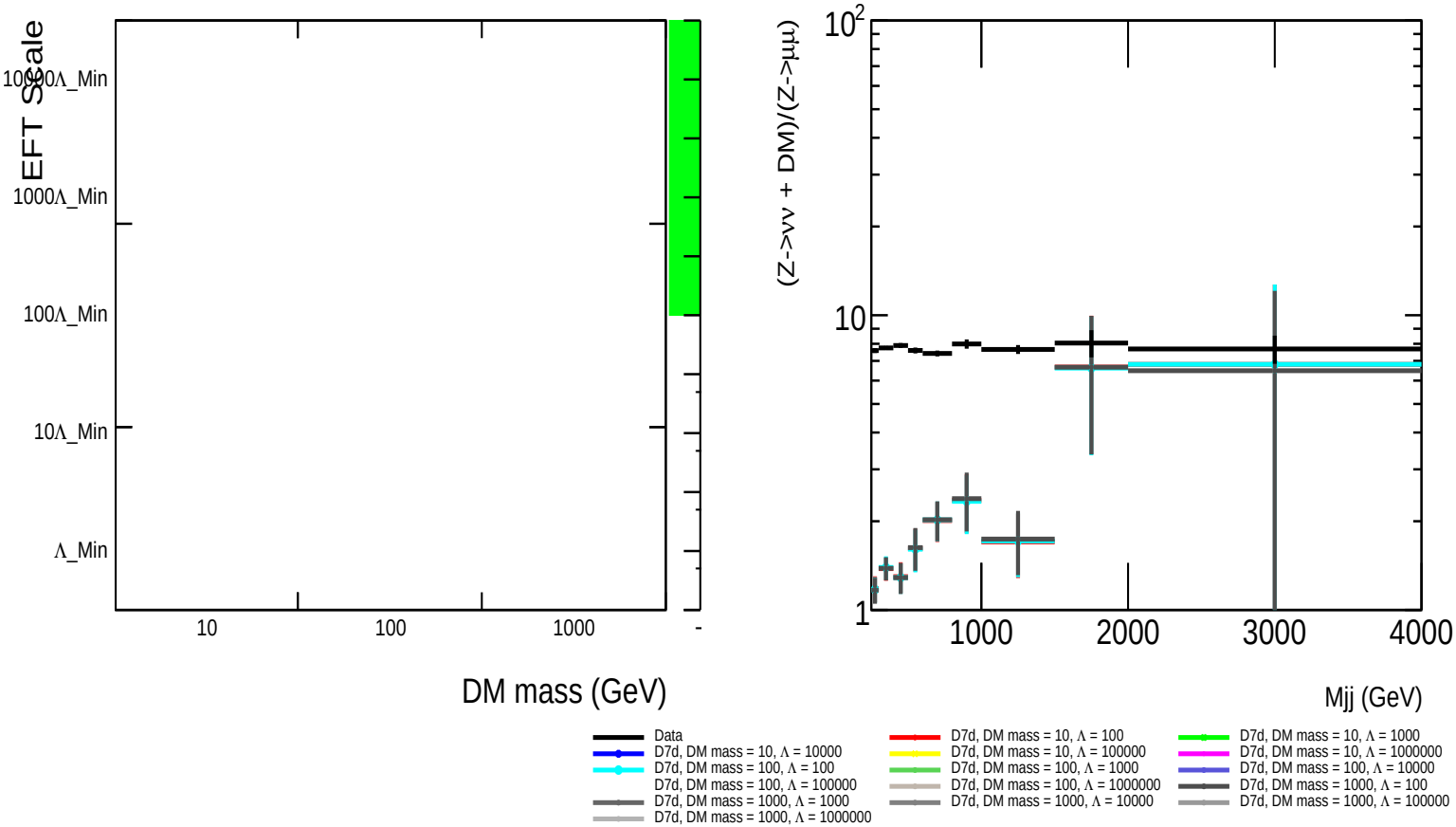
- The bins in the 2D histogram here haven't filled as the χ^2 p-value is so low.

Comparison: D7c : Mjj : $\Lambda_{Min} = 100$GeV



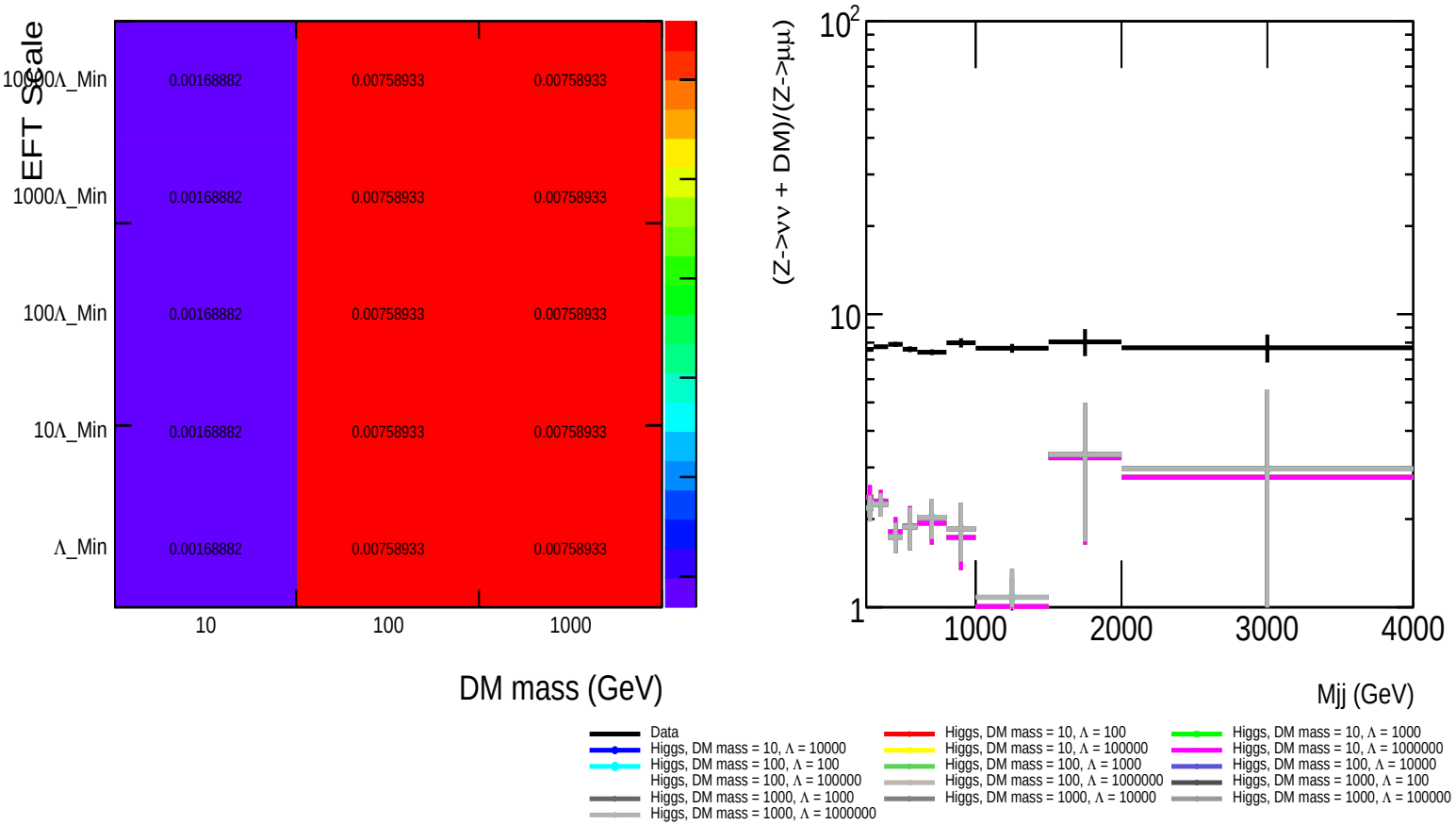
- The bins in the 2D histogram here haven't filled as the χ^2 p-value is so low.

Comparison: D7d : Mjj : $\Lambda_{Min} = 100$GeV



- The bins in the 2D histogram here haven't filled as the χ^2 p-value is so low.

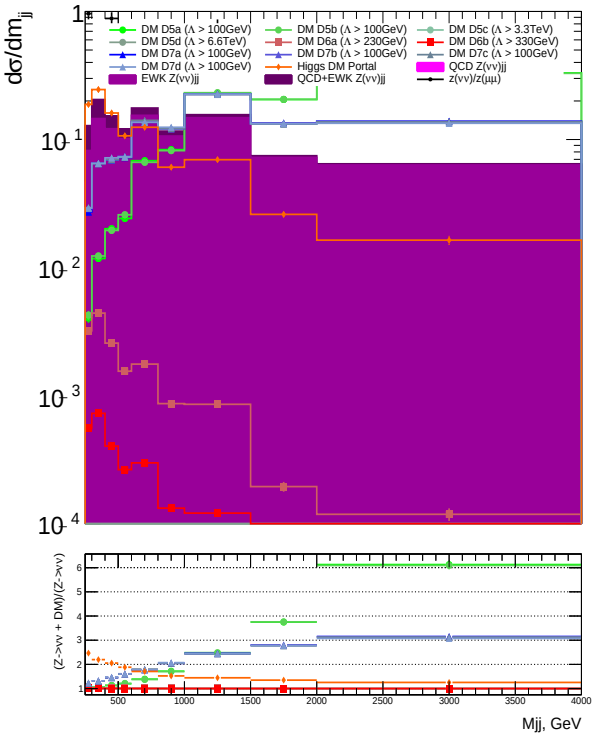
Comparison: Higgs : Mjj : $\Lambda_{Min} = 100GeV$



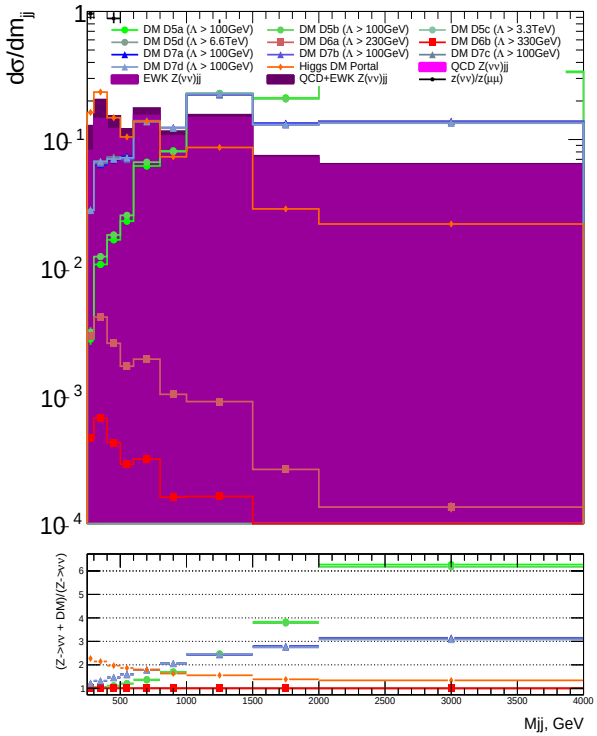
- The p-values here are much larger as the shape is flatter - closer to the shape of the data.

1D Histograms of Mjj for Different DM masses

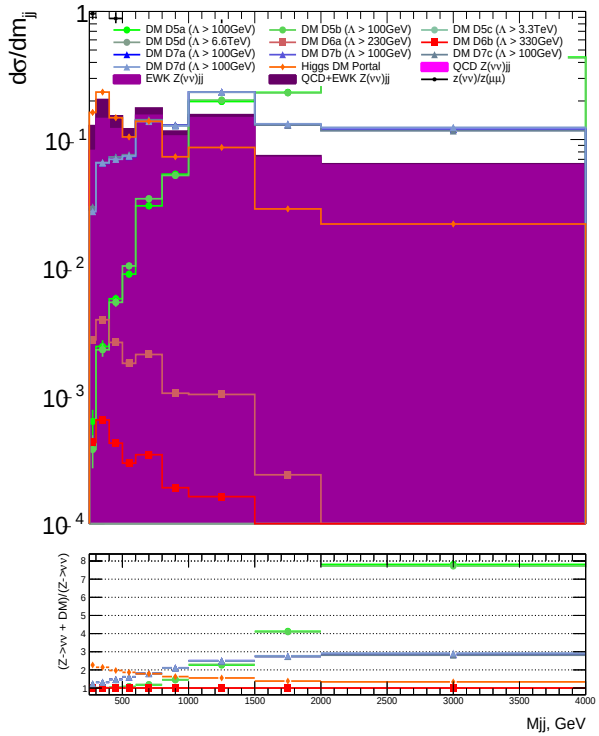
DM Mass = 10GeV



DM Mass = 100GeV



DM Mass = 1000GeV

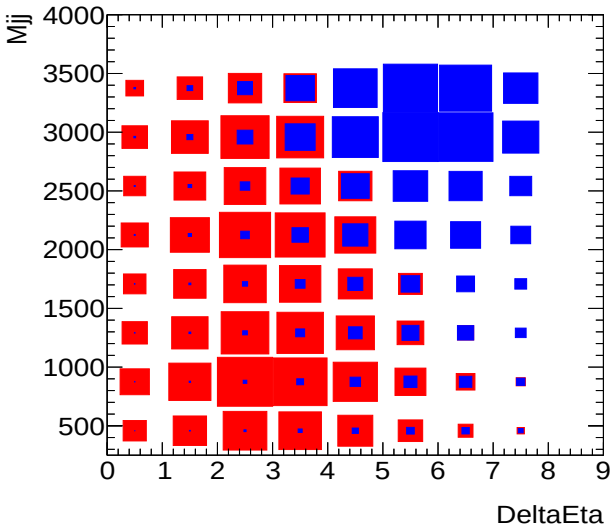


- Across all the masses, the Higgs 'dimension' is the most similar to the SM(Z$\rightarrow \nu\nu$)jj.

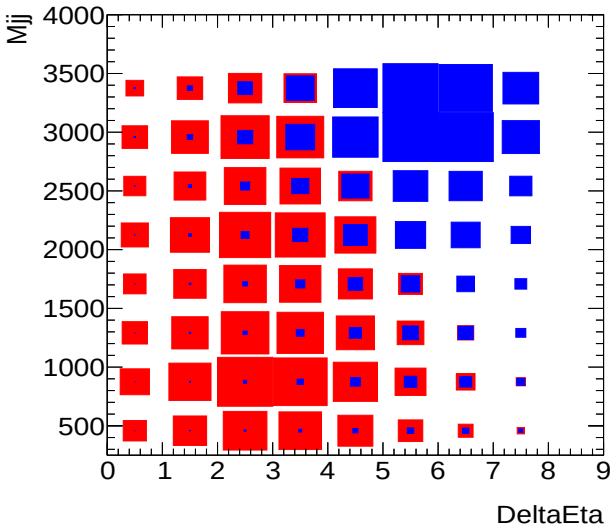
2D Comparison: $\Delta\eta$ vs Mjj : D5a

Red = EWK+QCD SM(Z$\rightarrow \nu\nu$)jj; Blue = DM model

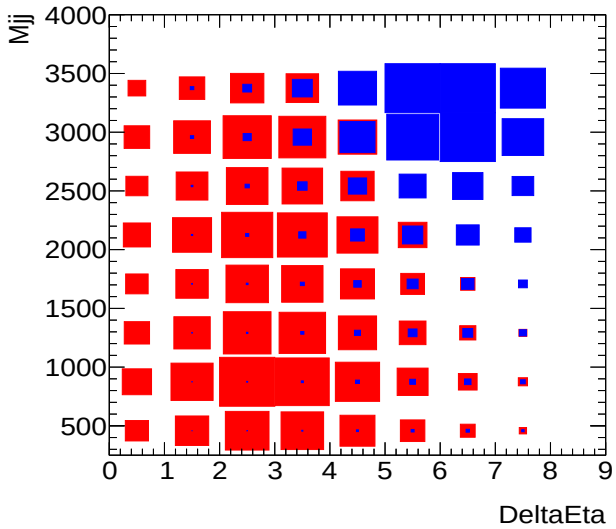
DM Mass = 10GeV



DM Mass = 100GeV



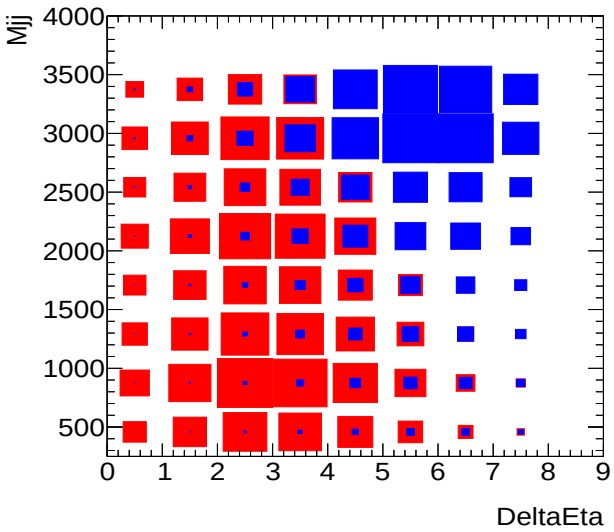
DM Mass = 1000GeV



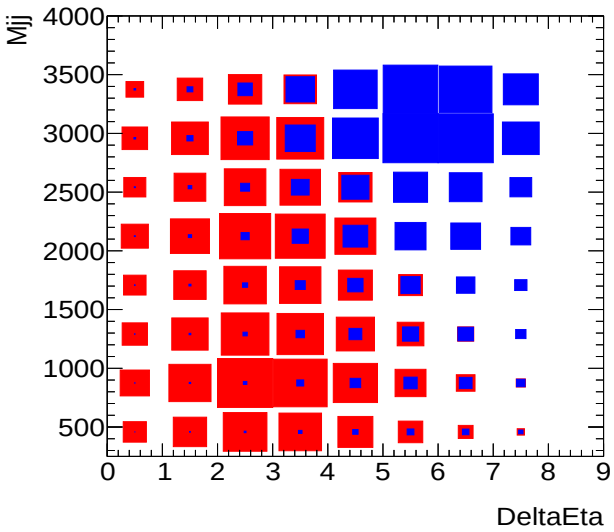
- Large difference between DM model and SM(Z$\rightarrow \nu\nu$)jj.

2D Comparison: $\Delta\eta$ vs Mjj : D5b

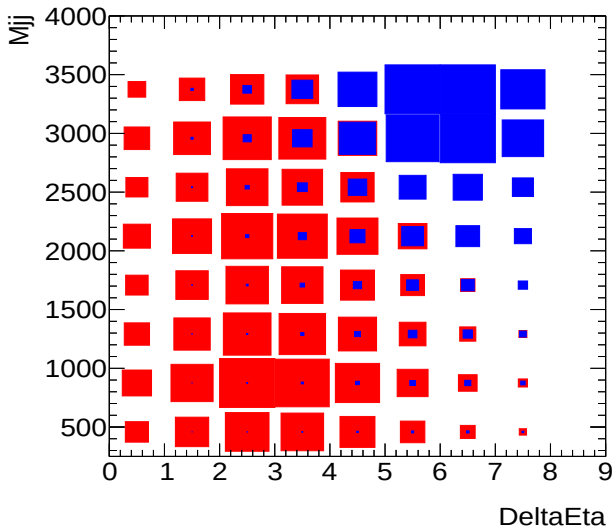
DM Mass = 10GeV



DM Mass = 100GeV

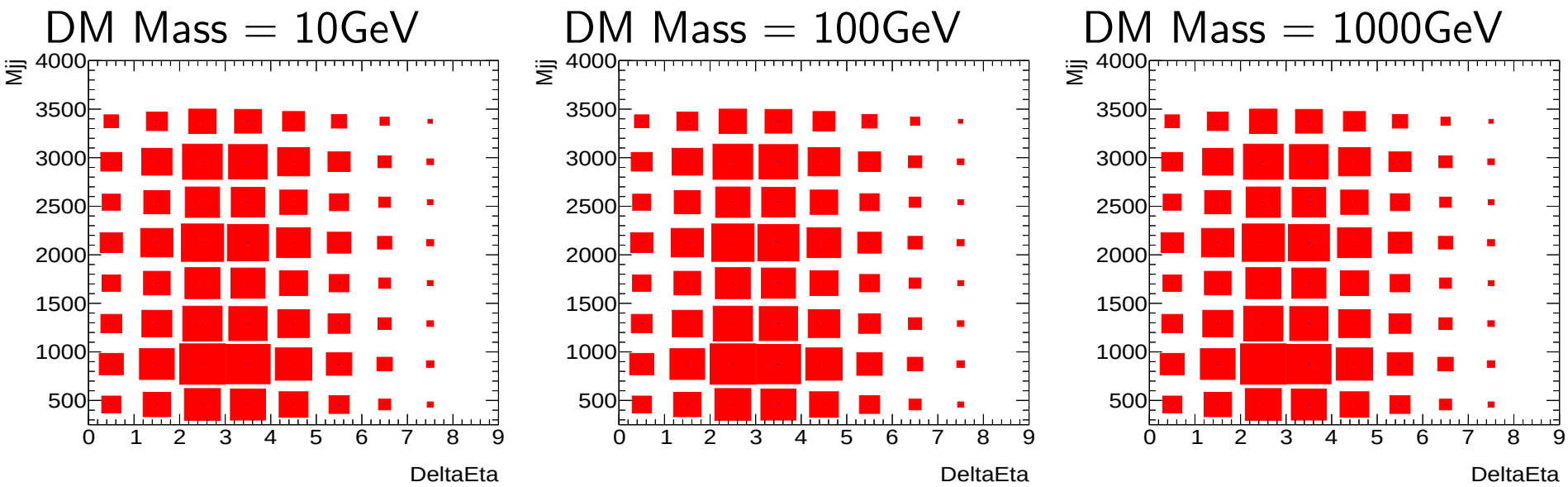


DM Mass = 1000GeV



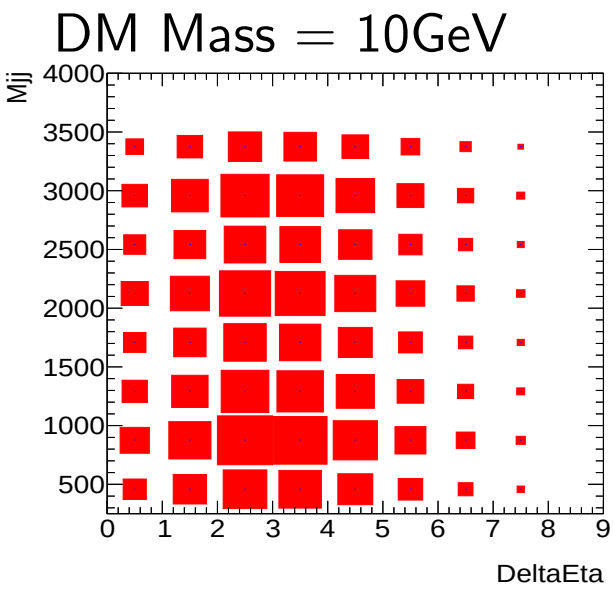
- Again : Large difference between DM model and SM(Z$\rightarrow \nu\nu$)jj.

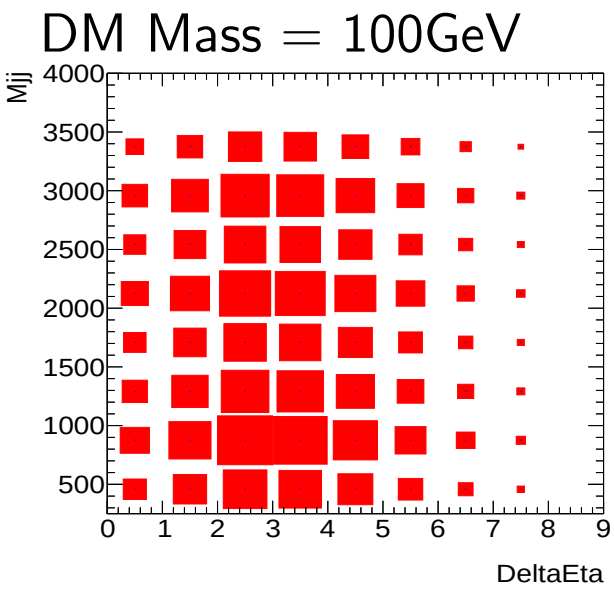
2D Comparison: $\Delta\eta$ vs Mjj : D5c

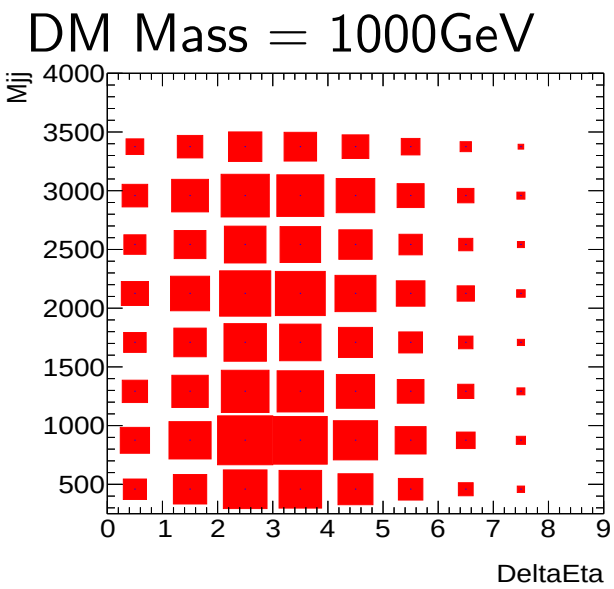


- Due to the large EFT constraint of $\Lambda = 3.3$ TeV, this dimension model can not be seen.

2D Comparison: $\Delta\eta$ vs Mjj : D5d

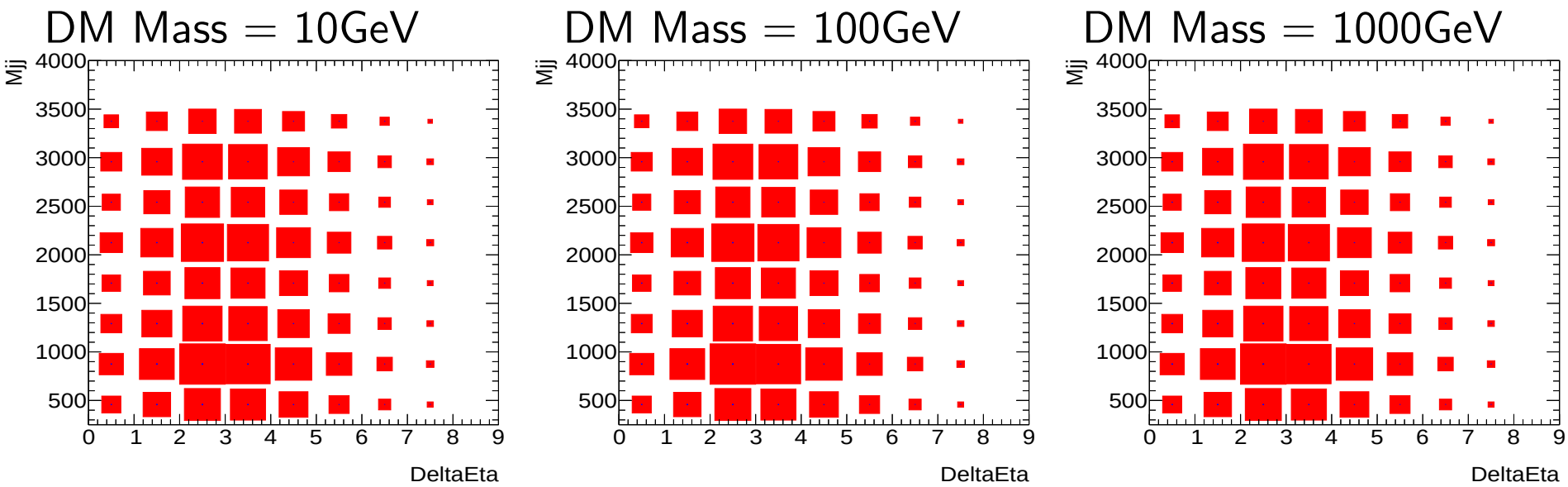






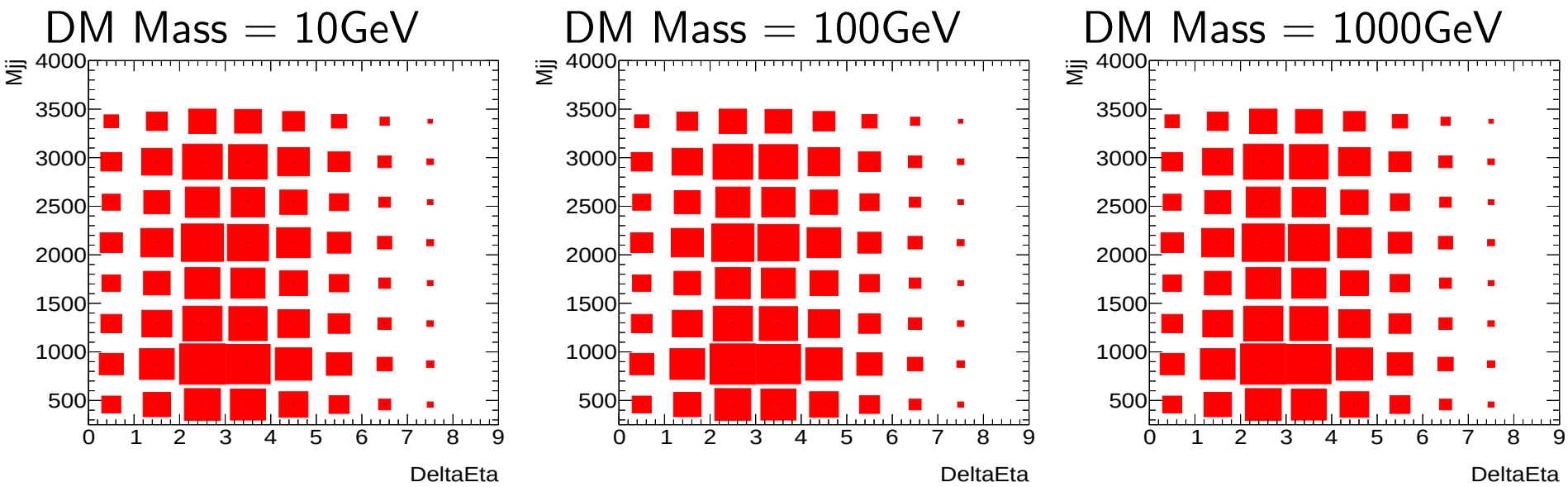
- Due to the large EFT constraint of $\Lambda = 6.6$ TeV, this dimension model can not be seen.

2D Comparison: $\Delta\eta$ vs Mjj : D6a



- Due to the large EFT constraint of $\Lambda = 330$GeV, this dimension model can not be seen.

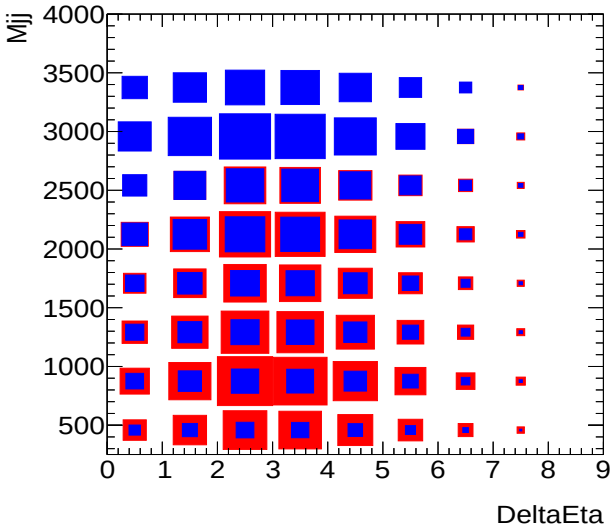
2D Comparison: $\Delta\eta$ vs Mjj : D6b



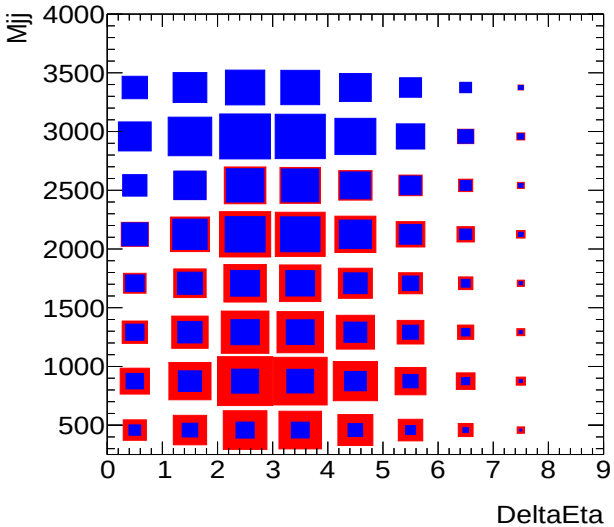
- Due to the large EFT constraint of $\Lambda = 230$GeV, this dimension model can not be seen.

2D Comparison: $\Delta\eta$ vs Mjj : D7a

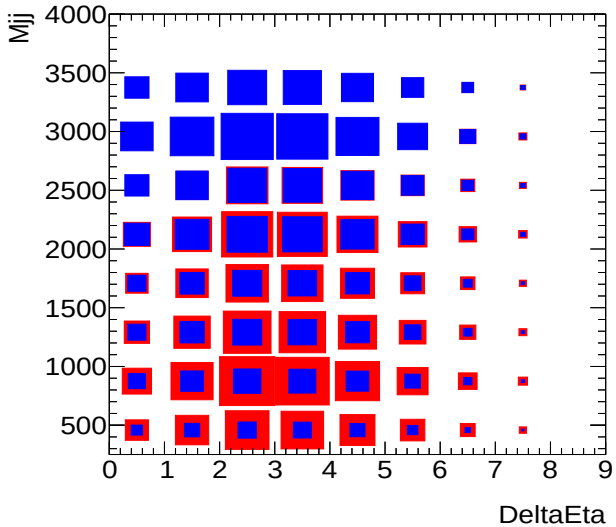
DM Mass = 10GeV



DM Mass = 100GeV

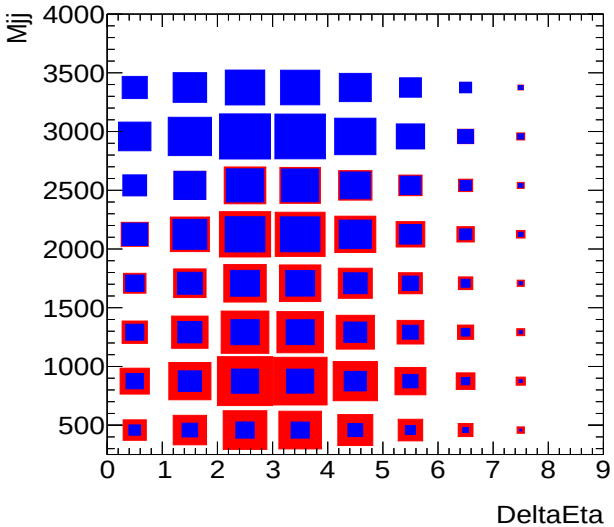


DM Mass = 1000GeV

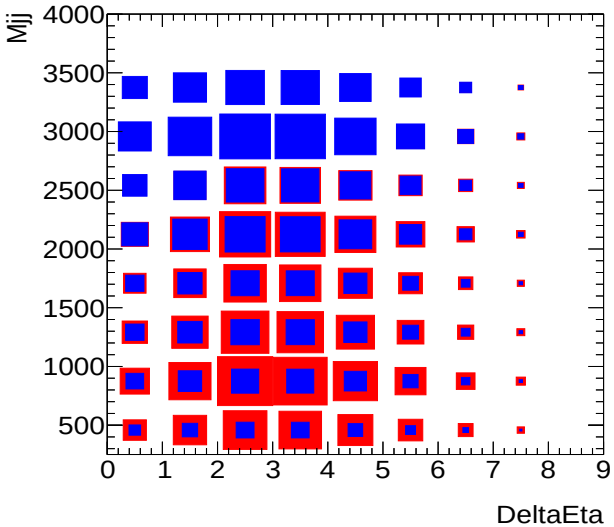


2D Comparison: $\Delta\eta$ vs Mjj : D7b

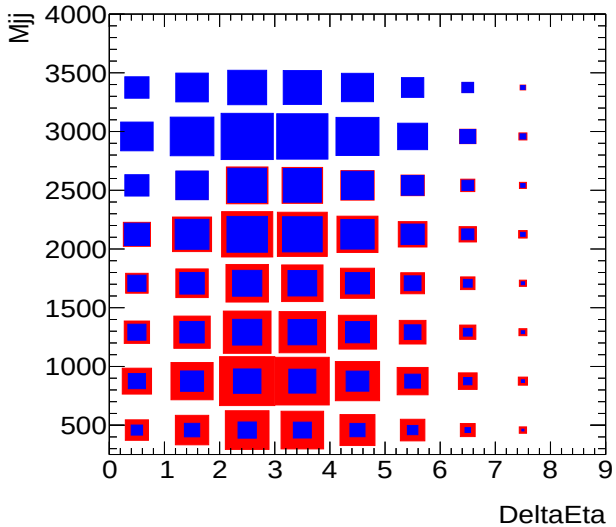
DM Mass = 10GeV



DM Mass = 100GeV

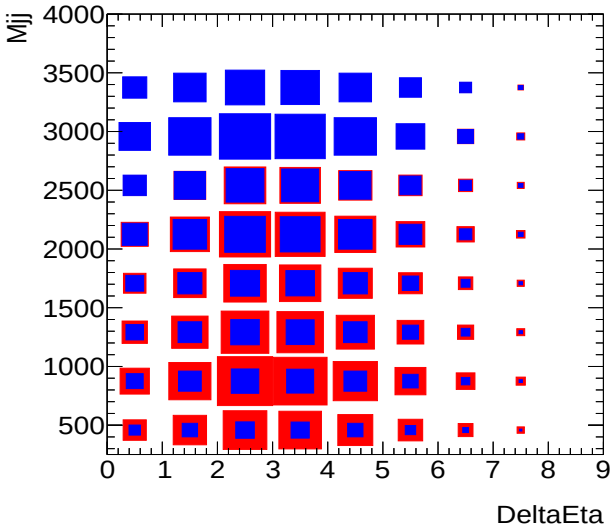


DM Mass = 1000GeV

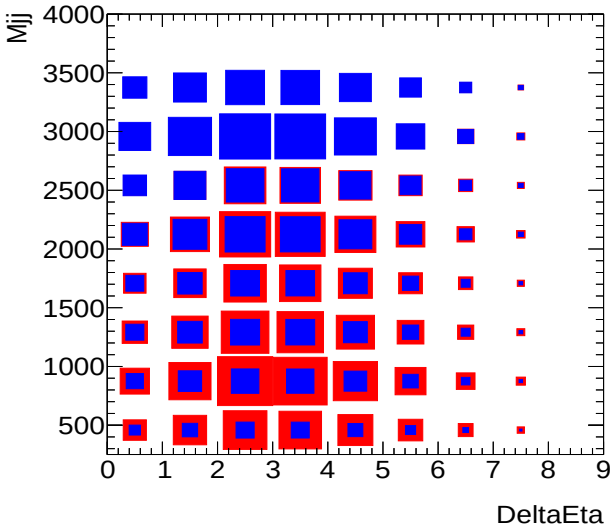


2D Comparison: $\Delta\eta$ vs Mjj : D7c

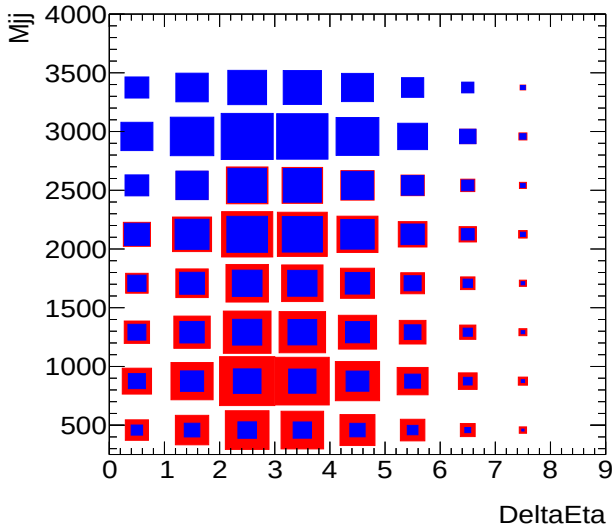
DM Mass = 10GeV



DM Mass = 100GeV

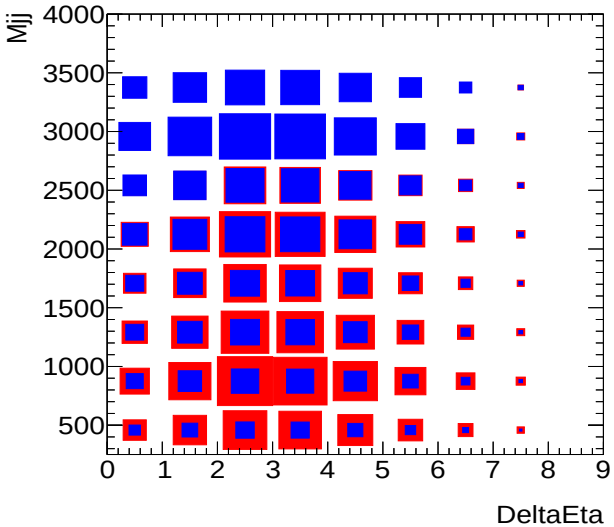


DM Mass = 1000GeV

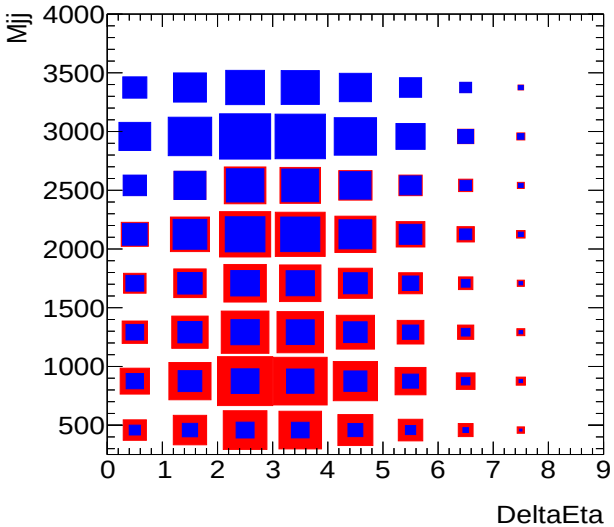


2D Comparison: $\Delta\eta$ vs Mjj : D7d

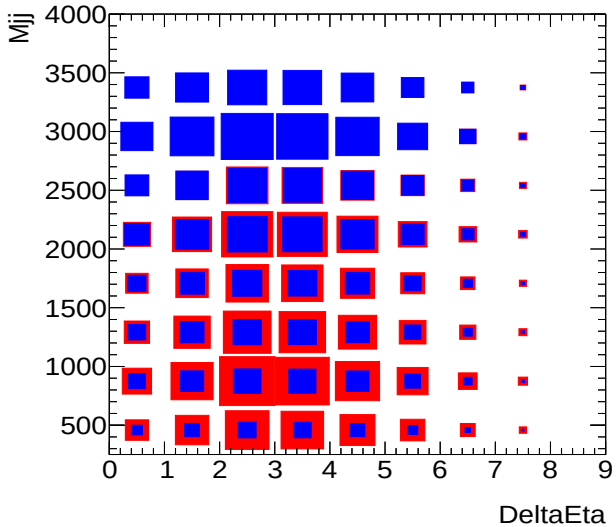
DM Mass = 10GeV



DM Mass = 100GeV

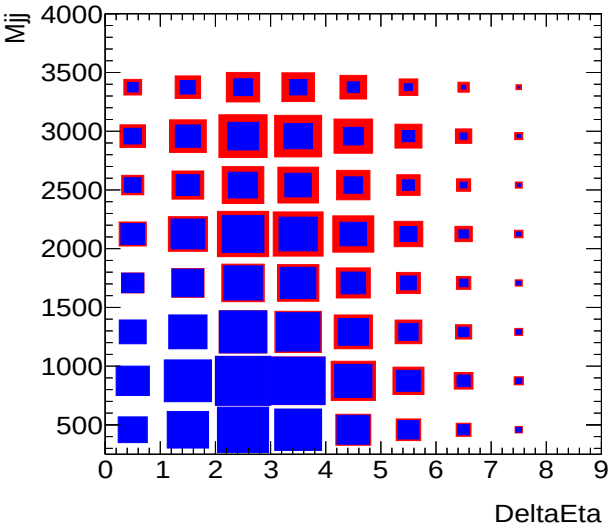


DM Mass = 1000GeV

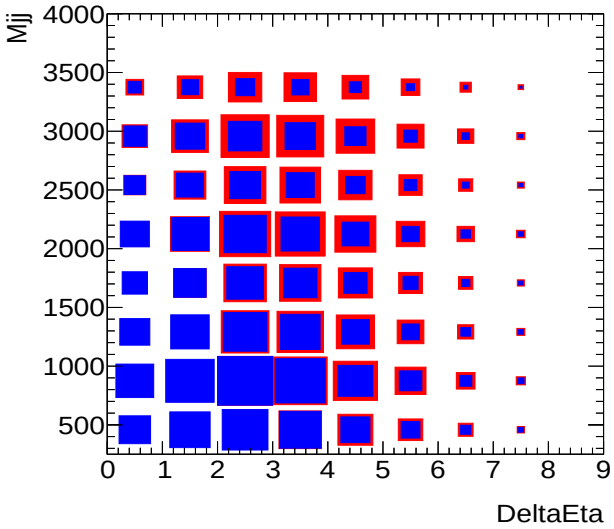


2D Comparison: $\Delta\eta$ vs Mjj : Higgs

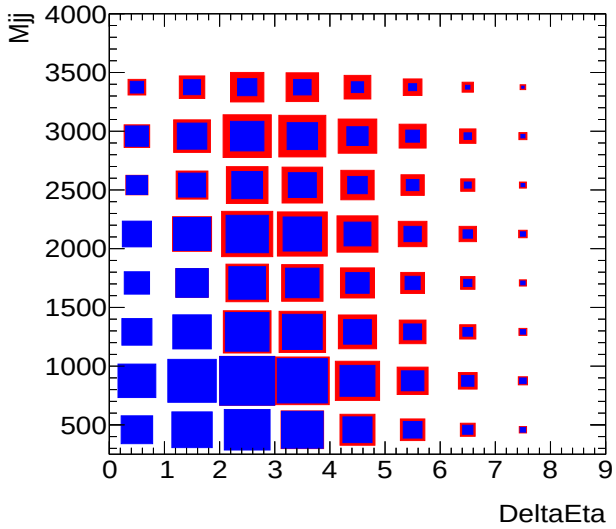
DM Mass = 10GeV



DM Mass = 100GeV



DM Mass = 1000GeV



- This lines up with the previous plots: The higgs 'dark portal' model is most like the SM(Z$\rightarrow \nu\nu$)jj.

Next Steps

- Fix bug in statistical test code that means the EFT Scale doesn't affect the p-value.
- Run more Masses through the code to compare in the statistics test.
- Add in a more robust statistical test.
- Run through procedure with Monojet and 'standard DM' models.