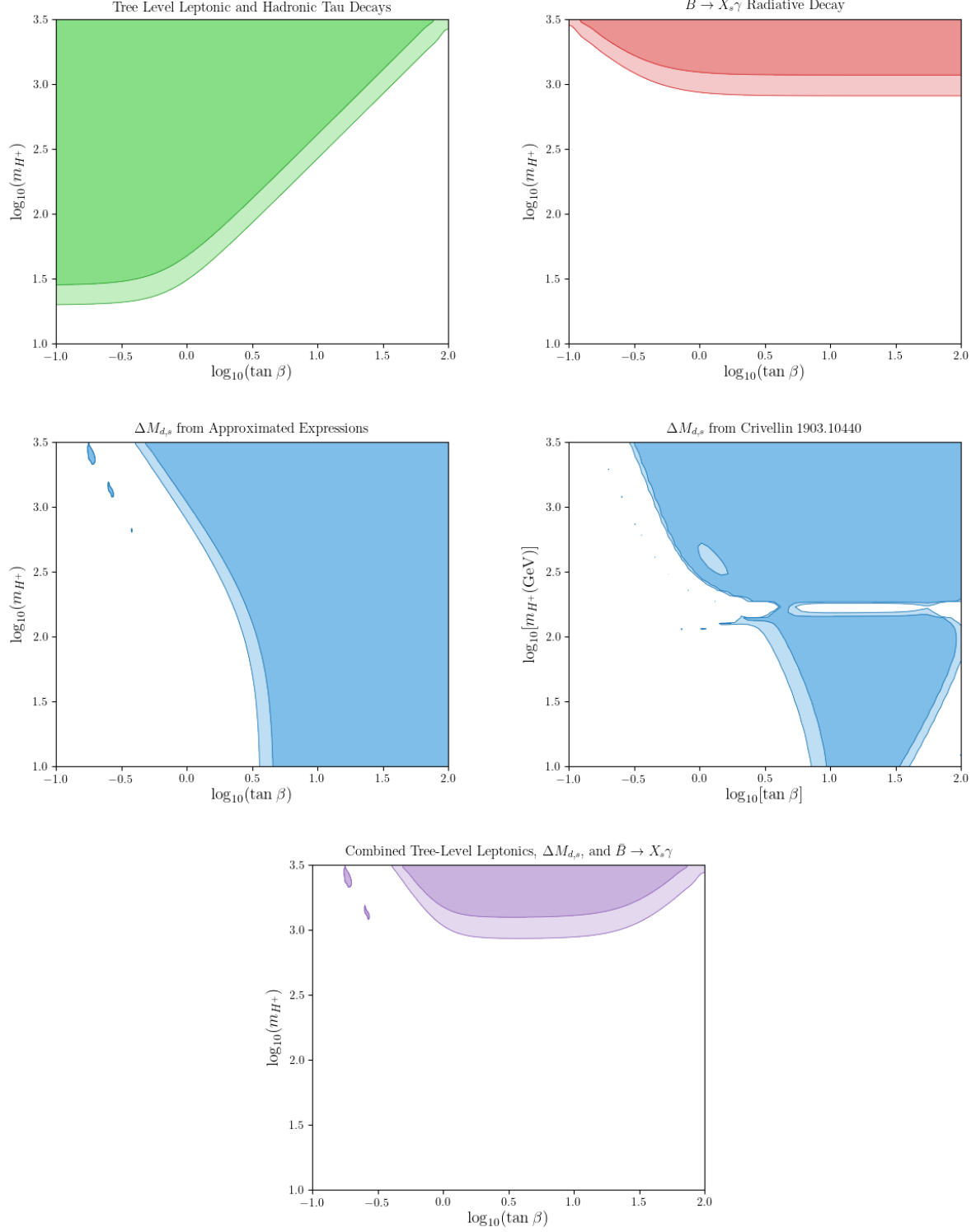# Project Notes

1 Replicating results

➤ Here are my plots for replicating what we did in first term:



➤ Like Oliver, the main difference seems to be with $b \to s\gamma$ where it fits higher than before – **the combined fit yields $m_{H^+} \gtrsim 970\,\text{GeV}$ at 2σ compared to $m_{H^+} \gtrsim \text{GeV}$ in my previous fits**

➤ *Note: all the plots here are showing contours for $1, 2\sigma$*

➤ I have modified the SM value in flavio for $b \to s\gamma$ to fit the current result of $(3.40 \pm 0.17)e^{-4}$ but still got this higher result

➤ It seems like it could be down to how flavio fits, but we would need to confirm this if we want to leave it as is

➤ I have also included the fit for B mixing from higher-order expressions in Crivellin 1903.10440 to show the difference

➤ Adding in $B_{s,d} \to \mu\mu$ and $\mathcal{R}(D^{(*)})$ yields similar results to what I had before
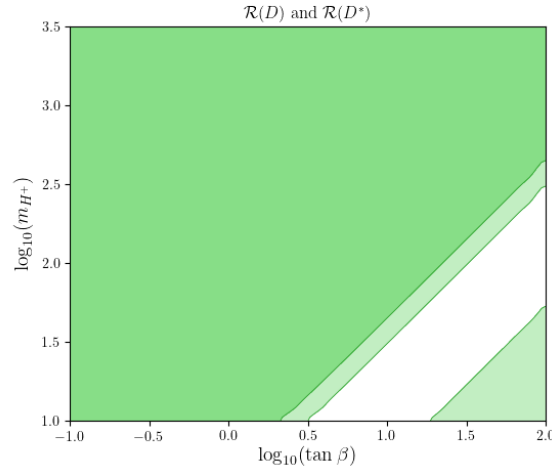
➤ $\mathcal{R}(D)$ and $\mathcal{R}(D^*)$ are fitting simultaneously it seems right now, which wasn't what we had before, so looking at individual plots:
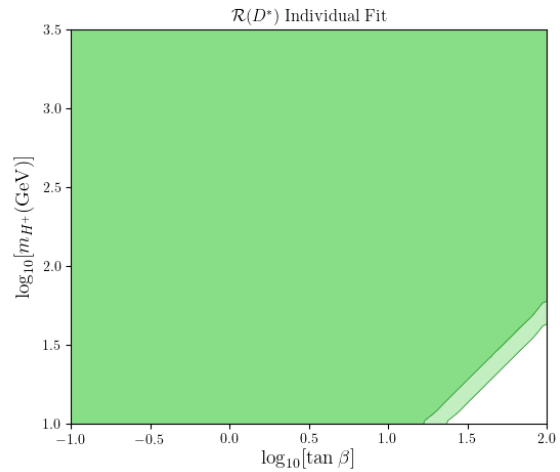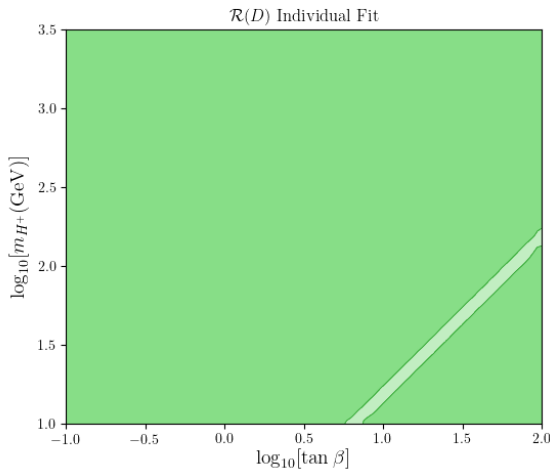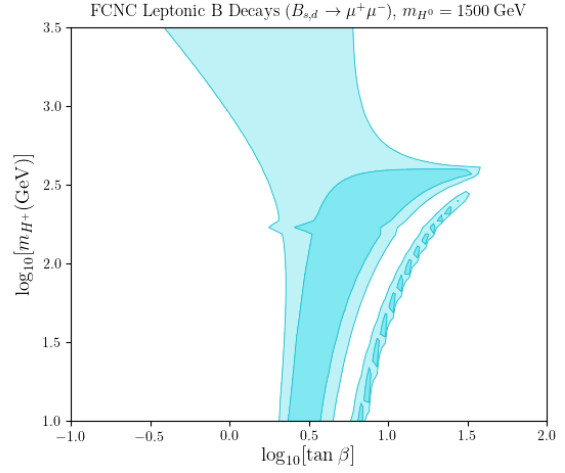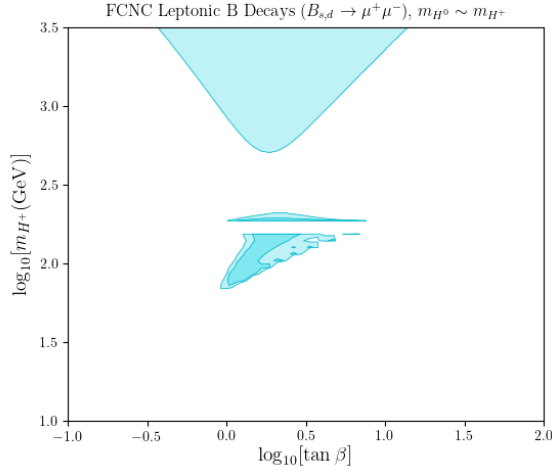

➤ It appears that both of them do fit individually which is not what we had before – I'm not quite sure why this is the case currently

➤ For $B_{s,d} \to \mu\mu$, the left diagram is approximating $m_{H^+} \sim m_{H^0}$ which is the rough limit James has from the obliques, and the right diagram is fixing $m_{H^0} = 1500\,\mathrm{GeV}$

➤ Using the convention from 1903.10440 for the trilinear couplings means that instead of using $M = m_{12}/(\sin\beta\cos\beta)$ as I did previously, you use λ_3 from the 2HDM potential

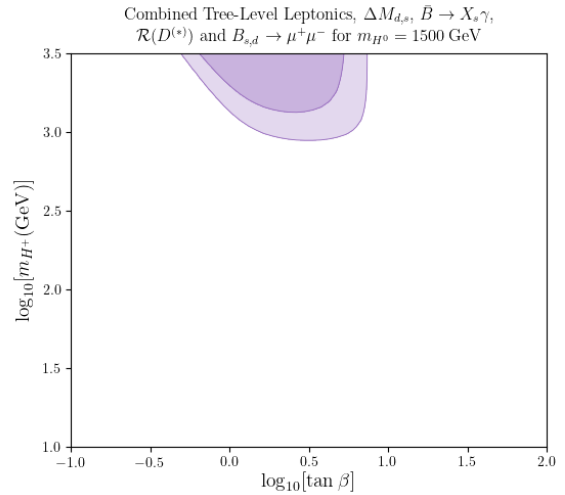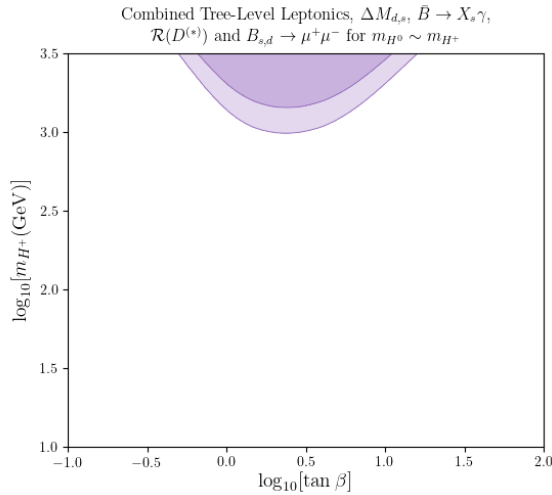➤ The two trilinear couplings we have to consider are

$$\lambda_{h^0 H^+ H^-} = v\sin(\beta - \alpha)\lambda_3, \qquad\qquad \lambda_{H^0 H^+ H^-} = v\cos(\beta - \alpha)\lambda_3$$

➤ In the alignment limit which I have been using so far for these, $\sin(\beta - \alpha) = 1$, so we only have to consider $\lambda_{h^0 H^+ H^-}$

FCNC Leptonic B Decays ($B_{s,d} \to \mu^+\mu^-$), $m_{H^0} \sim m_{H^+}$

FCNC Leptonic B Decays ($B_{s,d} \to \mu^+\mu^-$), $m_{H^0} = 1500$ GeV

➤ The contributions from the trilinear coupling seems to be minimal anyway, varying λ_3 from $0.01 \to 2$ doesn't change the results to any noticeable level, so for now I have set $\lambda_3 = 0.1$, but it's probably better to fit it properly at some point

➤ The coupling only contributes to C_S and C_P operators so far which only impact $B \to \mu\mu$

➤ Checking the combined fit for all these observables to compare to my overall project work (bar the inclusion of James' obliques):

Combined Tree-Level Leptonics, $\Delta M_{d,s}$, $\bar{B} \to X_s\gamma$, $\mathcal{R}(D^{(*)})$ and $B_{s,d} \to \mu^+\mu^-$ for $m_{H^0} \sim m_{H^+}$

Combined Tree-Level Leptonics, $\Delta M_{d,s}$, $\bar{B} \to X_s\gamma$, $\mathcal{R}(D^{(*)})$ and $B_{s,d} \to \mu^+\mu^-$ for $m_{H^0} = 1500$ GeV

➤ Left is approximating $m_{H^+} \sim m_{H^0}$ as above for $B \to \mu\mu$ (can't compare to project directly as didn't use this limit); right is fixing $m_{H^0} = 1500\,\text{GeV}$

➤ For the right, we have $m_{H^+} \gtrsim 970\,\text{GeV}$ and $\tan\beta \lesssim 7$; in my project for this, I had $m_{H^+} \gtrsim 500\,\text{GeV}$ and $\tan\beta \lesssim 21$

2 New Observables and To Do

➤ Also started looking at the tree-level semileptonic decays

➤ For semileptonics and leptonics, I think the WC contributions work out the same, e.g. for $b \to u\mu\nu_\mu$ (using the subscript convention from flavio's WET basis)

$$\mathcal{O}_{SR} = -\frac{4G_F}{\sqrt{2}}V_{ub}(\bar{u}_L b_R)(\bar{\mu}_R \nu_{\mu L}) \to C_{SR} = \frac{m_u}{m_{H^+}^2}$$

$$\mathcal{O}_{SL} = -\frac{4G_F}{\sqrt{2}}V_{ub}(\bar{u}_R b_L)(\bar{\mu}_L \nu_{\mu R}) \to C_{SL} = \frac{m_b \tan^2\beta}{m_{H^+}^2}$$

3

➤ For the tree-level leptonics, this transforms to r_H from 0907.5135, and looks to give the right results for semileptonics (including being used for the $\mathcal{R}(D)$s above)

➤ So providing the SM calculations for the semileptonics are fine, it's quite simple to fit these too:
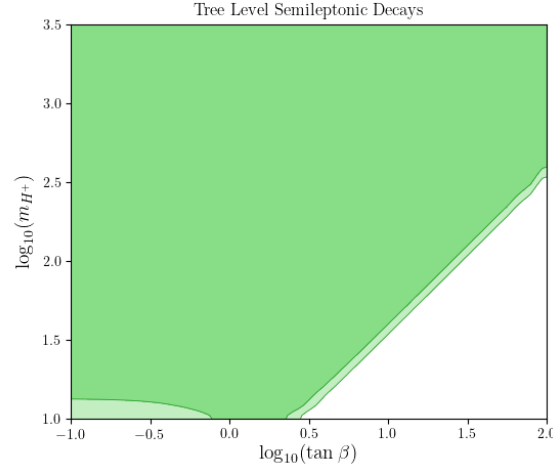
➤ The next thing is to look at R_K and R_{K*0}

➤ From 1704.05340, the operators needed for the R_Ks are $C_7, C_7', C_9, C_9', C_{10}, C_{10}'$ for both $bs\mu\mu$ and $bsee$

➤ All these can be got from 1903.10440 – already have the formulae for $C_{10}^{(')}$s from $B \to \mu\mu$ calculations

➤ For both $m_{H^+} \sim m_{H^0}$ and $m_{H^0} = 1500\,\mathrm{GeV}$ as I looked at $B \to \mu\mu$, we get no constraint in our parameter space from R_K and R_{K*0} (although I still need to check through all the formulae again for mistakes):
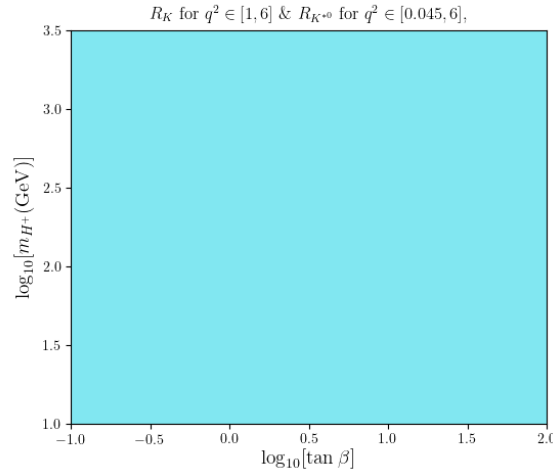
➤ I want to check in literature as well for the R_Ks in 2HDM Type II to see if there's any fits that include these to see what results have been found historically to give some at least a rough idea of what should be expected

➤ I will also look at fitting $b \to s\gamma$ using the expressions for C_7, C_8 in 1903.10440 since C_7 is in R_Ks anyway

➤ I need to do the fits including $B \to \mu\mu$ in the wrong sign limit too and compare to my previous results