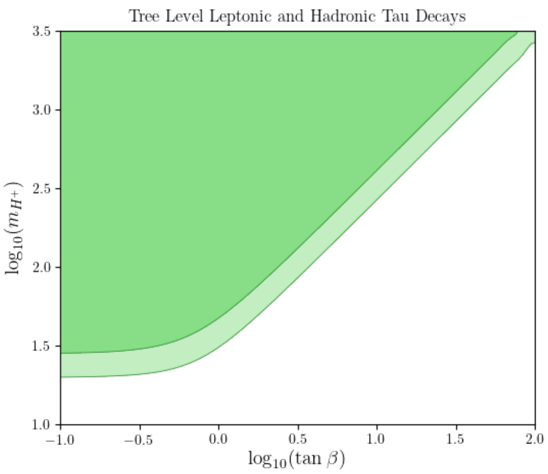
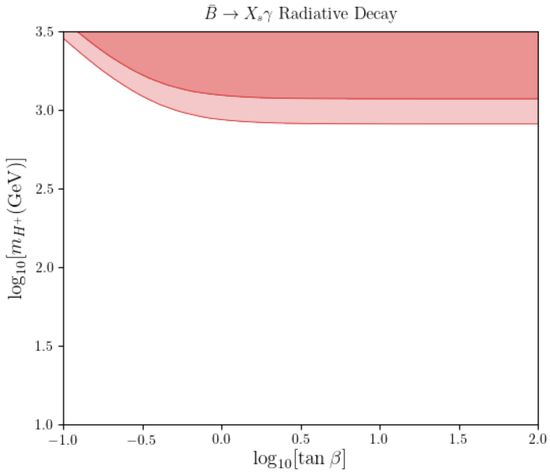
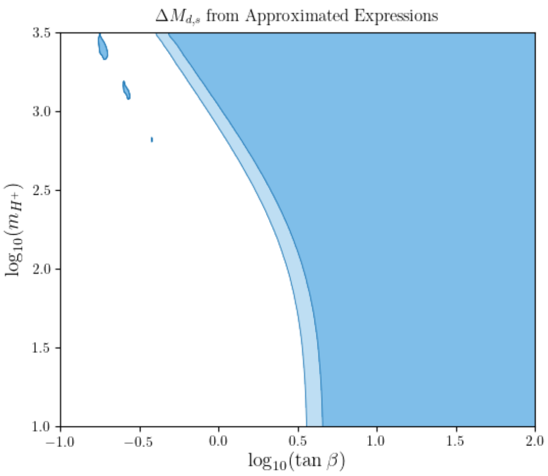
Project Notes

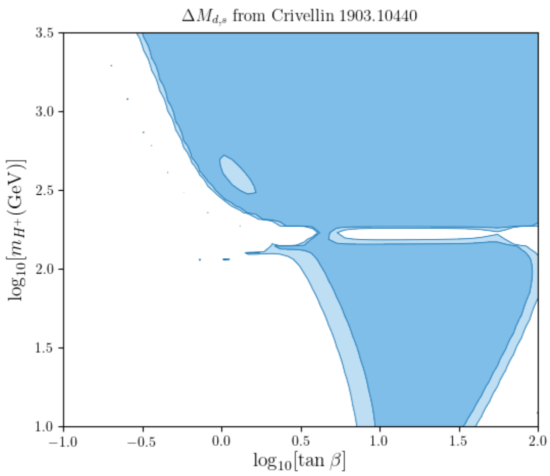
1 Replicating results

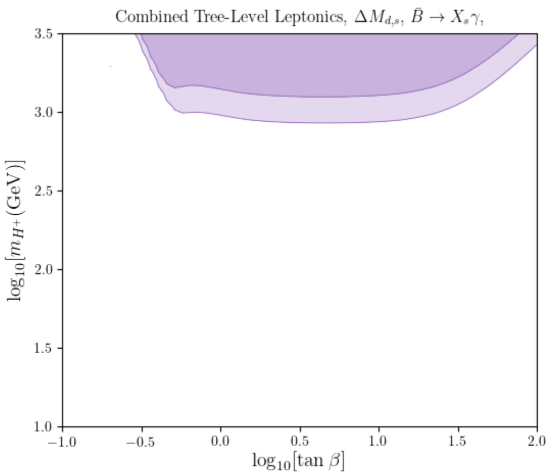
- ➤ Here are my plots for replicating what we did in first term:





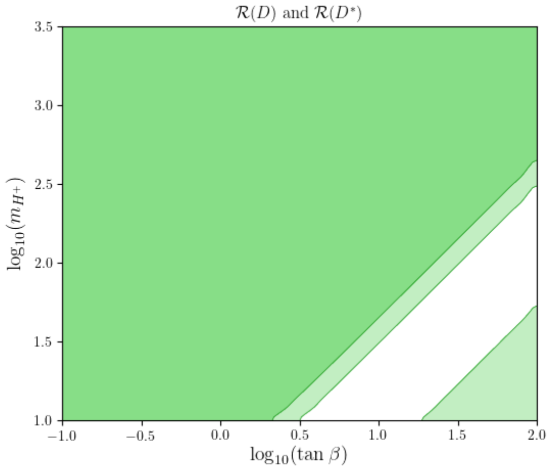




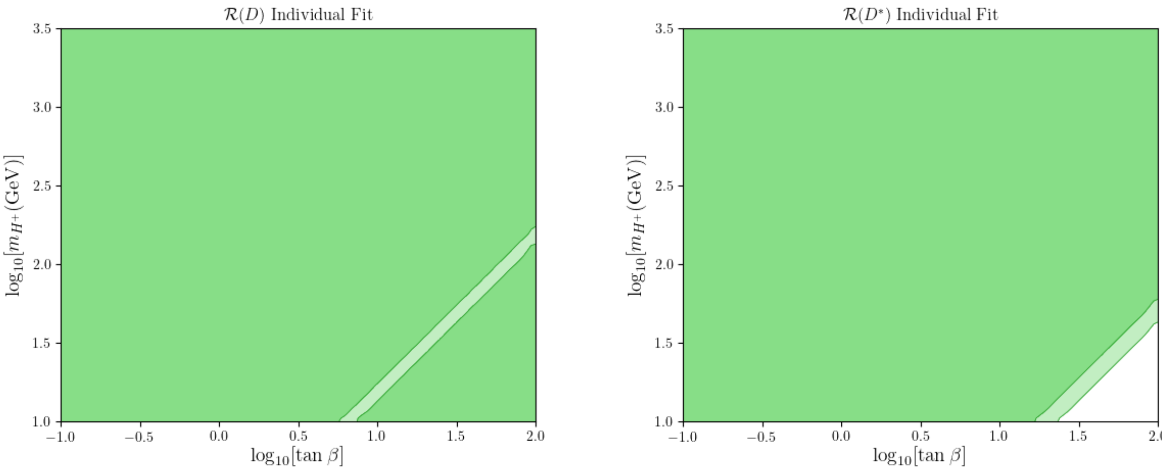


- ➤ Like Oliver, the main difference seems to be with $b \to s\gamma$ where it fits higher than before – **the combined fit yields $m_{H^+} \gtrsim 890$ GeV at 2σ compared to $m_{H^+} \gtrsim 500$GeV in my previous fits**
- ➤ *Note: all the plots here are showing contours for $1, 2\sigma$*
- ➤ This is using the higher order $b \to s\gamma$ expressions from Crivellin 1903.10440

- I have modified the SM value in flavio for $b \to s\gamma$ to fit the current result of $(3.40 \pm 0.17)e^{-4}$
- It seems like it could be down to how flavio fits, but we would need to confirm this
- I have also included the fit for B mixing from higher-order expressions in Crivellin 1903.10440 to show the difference – the gap we find around $m_{H^+} \sim m_t(m_t)$ is due to divergences in the loop functions for this value
- Adding in $B_{s,d} \to \mu\mu$ and $\mathcal{R}(D^{(*)})$ yields similar results to what I had before



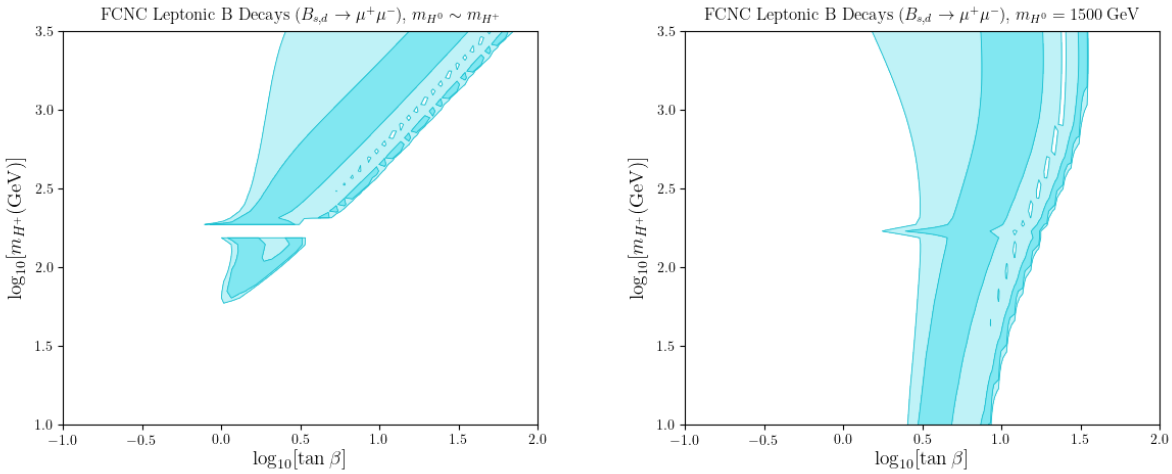
- $\mathcal{R}(D)$ and $\mathcal{R}(D^*)$ are fitting simultaneously it seems right now, which wasn't what we had before, so looking at individual plots:



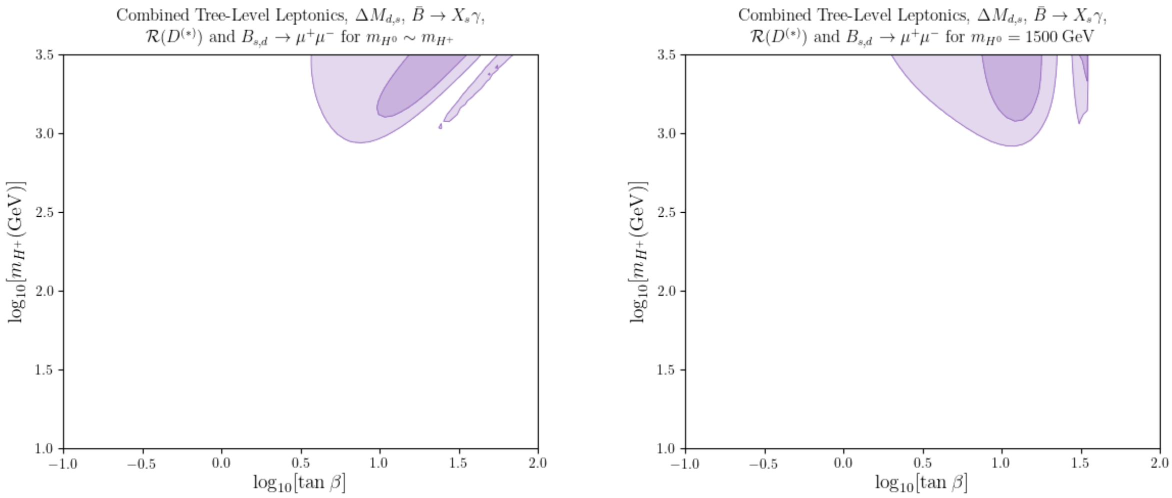
- It appears that both of them do fit individually which is not what we had before – I'm not quite sure why this is the case currently
- For $B_{s,d} \to \mu\mu$, the left diagram is approximating $m_{H^+} \sim m_{H^0}$ which is the rough limit James has from the obliques, and the right diagram is fixing $m_{H^0} = 1500\,\text{GeV}$
- 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

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

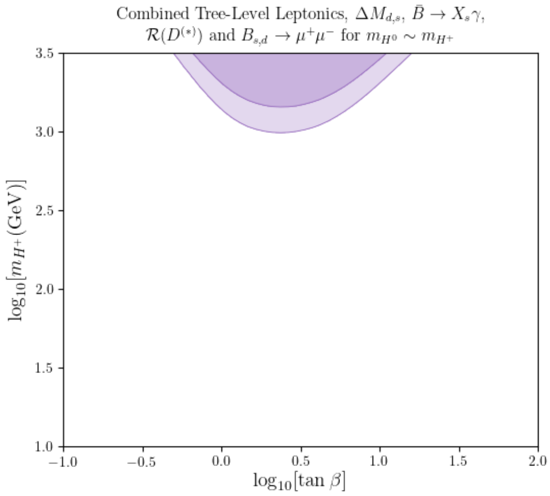
- In the alignment limit which I have been using so far for these, $\sin(\beta-\alpha) = 1$, so we only have to consider $\lambda_{h^0H^+H^-}$
- Using the updated values from Y Amhis at ICHEP 2020 and some code updates:

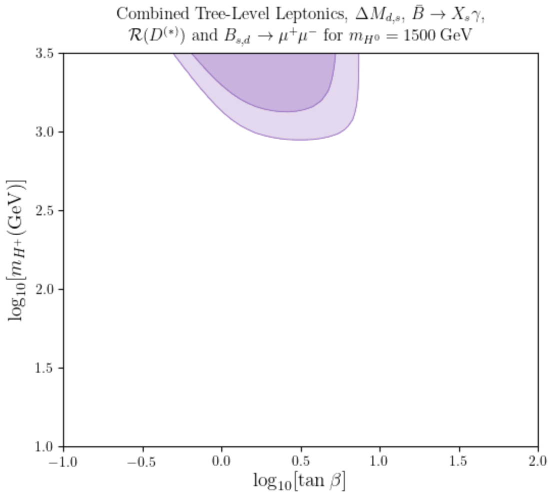


- ➤ These seem to preserve the overall shapes of the plots, but shifts constraints towards higher $\tan\beta$
- ➤ Updated global fits incoming to see the change there
- ➤ The contributions from the trilinear coupling seems to be minimal anyway, varying λ_3 from $0.01 \to 2$ doesn't change the results to any noticeable level, so for now I have set $\lambda_3 = 0.1$
- ➤ 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):



- ➤ 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 $m_{H^0} = 1500\,\mathrm{GeV}$
- ➤ For the left, we have $m_{H^+} \gtrsim 890\,\mathrm{GeV}$, $\tan\beta \gtrsim 3.4$
- ➤ For the right, we have $m_{H^+} \gtrsim 890\,\mathrm{GeV}$, $\tan\beta \lesssim 35$; in my project for this, I had $m_{H^+} \gtrsim 500\,\mathrm{GeV}$ and $\tan\beta \lesssim 21$
- ➤ Interestingly, these new plots are beginning to look more similar to my very early work using $B \to \mu\mu$ in the large $\tan\beta$ limit
- ➤ Below are the old plots for comparison to the above
- ➤ The constraints on m_{H^+} have not changed at all since this primarily comes from $b \to s\gamma$, but the constraints on $\tan\beta$ have been significantly shifted to the right



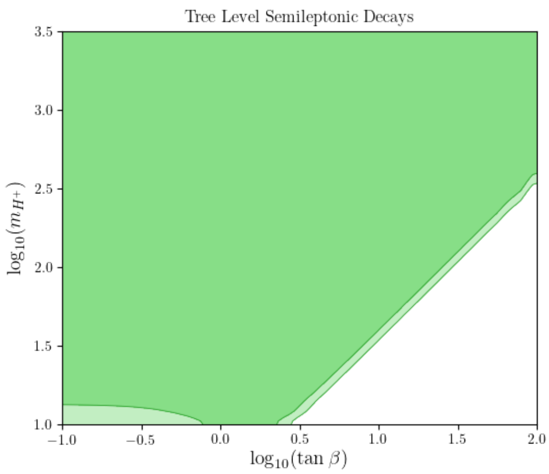


2 New Observables and To Do

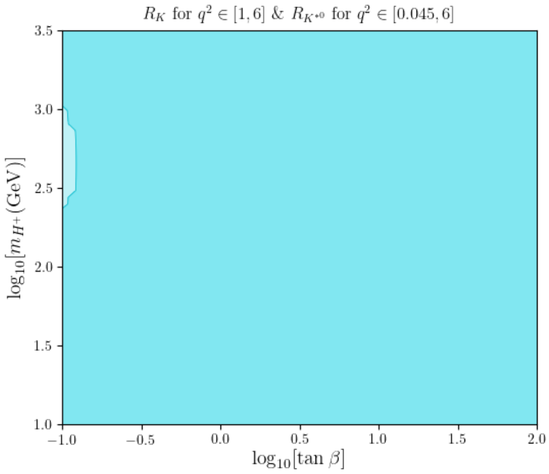
- Also started looking at the tree-level semileptonic decays
- For semileptonics and leptonics, I think the WC contributions work out the same, e.g. for $b \to u\mu\nu_\mu$ (using the subscript convention from flavio's WET basis)

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

- 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 $bsee$ – I think we also need to consider C_8, C_8' so these are also calculated and included in my fits
- All these can be taken from 1903.10440 – the only new WCs are C_9, C_9' as the others are included in $b \to s\gamma$ and $B \to \mu\mu$
- So far, we get essentially no constraint in our parameter space from R_K and $R_{K^{*0}}$:



- There still needs to be more checks in case I've missed something, but so far we see a small region excluded at 1σ in the left of the plot and that's it
- I want to check in literature 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 have looked at the fit for the R_Ks in 2007.11942 and it's not the easiest to compare to, but it looks like they've found only a small constraint from R_Ks near what would be along the left axis of our plots, which is roughly similar to where we're beginning to see a constraint here
- I need to do the fits including $B \to \mu\mu$ in the wrong sign limit too and compare to my previous results