Result and Discussion

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Don't use passive voice -- it's OK to say "I used DirectDM". It is much clearer that way.

DirectDM was used to take as input the Wilson coefficients describing dark

reference?

matter particle interacting with quarks, and RG evolve the coupling down from electroweak scale down to nucleus scale. Heavy quarks were integrated out during the process and matched from 5-flavour basis into 4-flavour basis, and then matched from 4-flavour basis into 3-flavour basis at respective scale.

you need to explain what 5,4,3-flavour basis actually means

Not clear what this means

reference

DDCalc was then used to calculate detection rates. The match result of EFT Wilson coefficients from DirectDM were then taken as input and DDCalc provides the non-relativistic matching and the expression of the nuclear responses. Xenon1T(2018) data were then compared to the result of the expected rate calculation.

Explain how you modified DDCalc to deal with inelastic scattering; it's important for the markers to realise that you extended the code yourself, and that you didn't just use it like a black box.

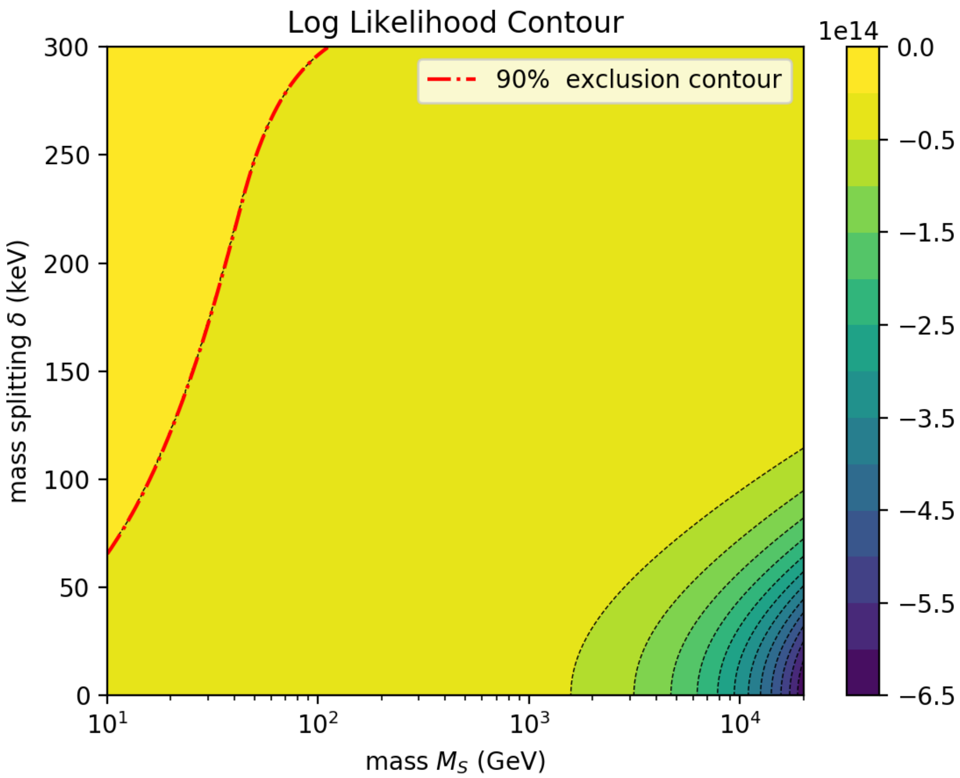

Figure 1: Log Likelihood against Mass of DM and Mass S (or A) and Mass Splitting between S and A

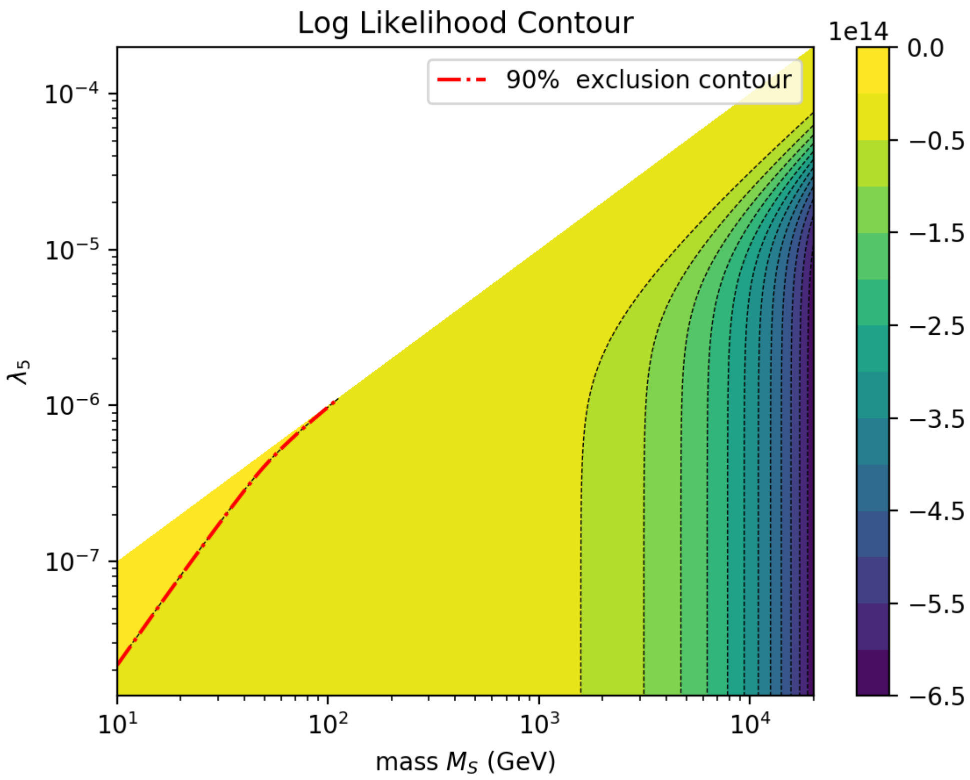

Figure 2: Log Likelihood against Mass of DM and Mass S (or A) and coupling constant λ_5

From the discussion of inelastic dark matter, we see that parameters that are relevant, and therefore can be constrained by ~~constraint from~~ direct detection are ~~is~~ the mass splitting δ and mass of dark matter M_S or M_A. The relationship between δ and parameters in the model is

you need to say that it is the SDDM model you are talking about here

$$\lambda_5 = \frac{2M_S\delta}{v^2}$$

where λ_5 is one of the coupling strength of four-vertex between χ and Higgs $\chi\chi \to H^\dagger H^\dagger$. In the limit of $\lambda_5 \to 0$, there would be no mass splitting between S and A. The two degrees of freedom is just the complex χ_0 field and its conjugate $\bar{\chi}_0$. Figure (1) and (2) shows the lower bound on this DM number violating processes. It shows that low-δ region has been completed ruled out in the SDDM case.

Figure(1) shows the results from scanning over the mass splitting and the dark matter mass. Figure (2) shows the results from scanning over the λ_5 and M_S, the two parameters from the model. The red exclusion curve represents at 90 percent confidence the DD experiment rules out the model in the region with darker colours. The bright yellow region means the parameter values

it just means that they are allowed by the XENON1T results; it does not

survive the exclusion and are subject to other constraints.

necessarily mean they are subject to other constraints -- it means one should test them against other constraints though.

In Fig (1), the log-likelihood plot is a non-linear mapping of Fig. (2) into

this seems the wrong way around -- Fig 2 is a non-linear projection of Fig 1 into the M_S -- lambda_5 plane

a projection M_S-λ_5 plane of the original parameter space. The white region represents the fact that no constraints about this model can be learnt from DD experiment, simply because mass splitting is too large compared to the typical momentum exchange. The inelastic scatter then become impossible.

check the max mass splitting that can be constrained by a xenon experiment. You should comment on what other material might be better to constrain higher mass splittings.

The degrees of freedom the direct search of DM can explore is essentially two, the DM mass M_S and δ, which are two projected degrees of freedom in the original parameter space. In terms of those parameters, M_S is $M_\chi^2 + (\lambda_3 + \lambda_4)\frac{v^2}{2}$ and δ is $\frac{\lambda_5 v^2}{2(\sqrt{M_\chi^2 + (\lambda_3+\lambda_4)\frac{v^2}{2}})}$. These are essentially the two degrees the DD experiments are exploring. These constraints shown in Fig (1) is then mapped back to original parameters in Fig (2).

M_S isn't really original...

For FDDM, the mass splitting δ is due to a small Majorana mass, and is proportional to the induced vev acquired by the Δ

$$m = \sqrt{2} g_2 < \Delta^0 >$$

and

$$\delta = 2m$$

therefore δ is directly proportional to one of the model parameter, i.e. $\langle \Delta^0 \rangle = \frac{\delta}{2\sqrt{2} g_2}$.

The FDDM plot Fig (3) and Fig (4) show that mass range of 40-60 GeV being most strongly suppressed, due to the sensitivity from the DD

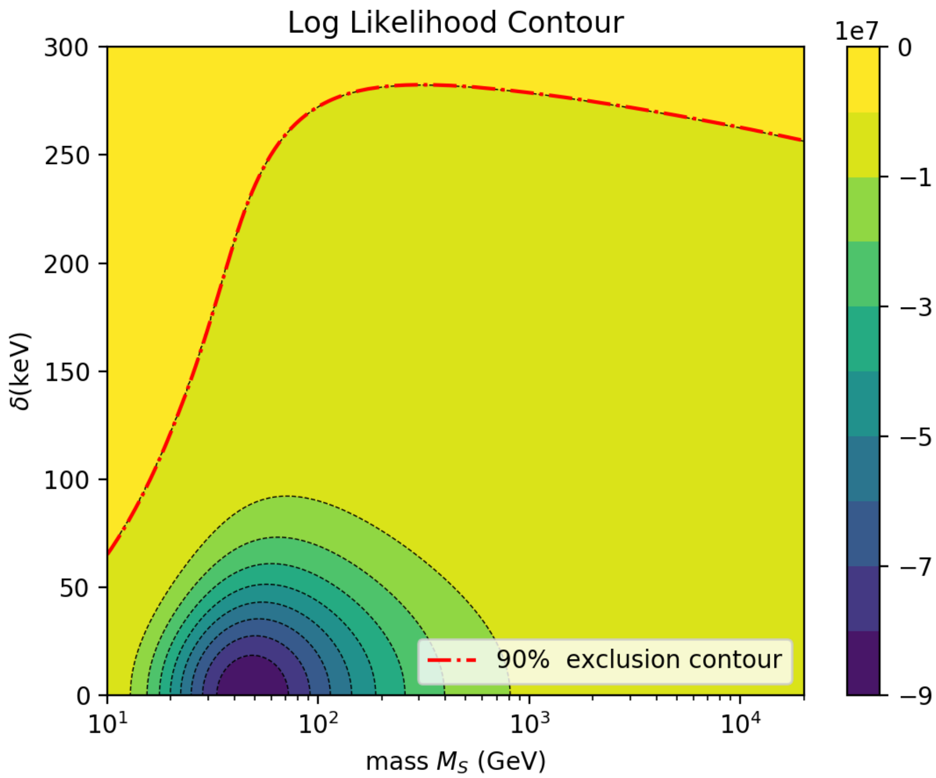

Figure 3: Log Likelihood against Mass of DM and Mass S (or A) and Mass Splitting between S and A

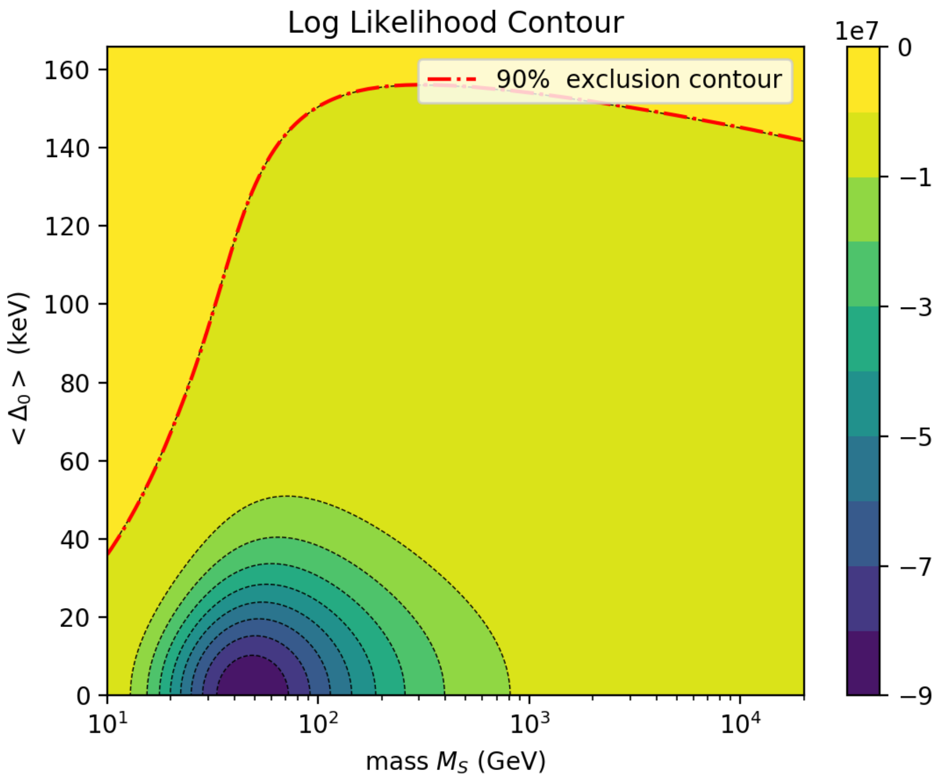

Figure 4: Log Likelihood against Mass of DM and Mass S (or A) and Vev of neutral Δ component

experiment. Fig (3) shows the scanning over the mass splitting and the dark matter mass. Fig (4) shows the scanning over the $\langle\Delta_0\rangle$ and M_D. The simple relationship between fermion mass splitting and vev of neutral component of scalar triplet means the coincidence of these two plots. The upper bright yellow region is the region that survives the new data from DD experiment. It can be seen that δ needs to be non-zero in the whole weak scale mass range for this model to work. The strongly restricted yellow region represents that the null result of DD experiment requires the model predicts very few events in order to work. The dark green region is where this model predicts huge number of events and therefore extremely disfavoured.

You might want to have two versions of these plots, showing different colour bands. The versions you have do illustrate your point about matching the mass sensitivity of XENON1T very well, so I think this is worth keeping -- but the really interesting range of likelihoods is the one around the contour, as we discussed. Also, try to add a paragraph or two discussing how else we could constrain the remaining part of the parameter space, using probes other than direct detection. Try to make some back-of-the envelope estimates of which probes should be sensitive to what ranges of the model parameters.

2 Conclusion

I suggest to make the conclusion a separate chapter, even if it is just a short one.

The small mass splitting (i.e. small λ_5) region is completely ruled out by DD experiments at 90 percent confidence. For SDDM high-mass low-splitting region is most strongly disfavoured. For FDDM, low-splitting 50 GeV mass region is most strongly disfavoured. Based on the null results from XENON1T(2018), these regions in log-likelihood plot is tremendously suppressed. In the SDDM case, this is related to the matching between the relativistic EFT describing DM interacting with five flavours of quarks at electroweak scale, and the non-relativistic EFT describing DM with nucleons. Ultimately this is related to the 4-momentum dependence from the derivative coupling. This translated into prediction of larger coupling between DM and SM at higher DM mass. In the FDDM case, the region of suppression in the log likelihood is coincident with the sensitivity of the DD experiment.

The results of the parameter scanning show that severe constraints were put on this model in the 2D projection of the parameter space. Without the inelastic DM, XENON1T(2018) results almost have ruled out the whole possible mass range of WIMP in this model. Inelastic DM were introduced to accommodate conflicting result from DD of DM and annual modulation

Mention again though that the non-zero mass splitting is important in this model to explain neutrino masses.

experiment. Relic-density calculation can gives further constraints based on the dark matter density. Whether this model survives full-parameter scan under collider physics and indirect detection constraints requires further analysis.