# BSM Explanations of $a_\mu$ in light of FNAL muon $g-2$ measurement

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https://doi.org/10.1007/JHEP09(2021)080

## Introduction

- Recently Fermilab released the results of their first experimental run for measuring the anomalous magnetic moment ($a_\mu$) of the muon.
- When combining the results of the Fermilab and Brookhaven experiments, we find that the experimental value:

$$a_\mu^{2021} = (116592061 \pm 41) \times 10^{-11} \qquad (1)$$

and the standard model value: :

$$a_\mu^{\mathrm{SM}} = (116591810 \pm 43) \times 10^{-11} \qquad (2)$$

disagree by $\Delta a_\mu^{2021} = (25.1 \pm 5.9) \times 10^{-10}$, a discrepancy of $4.2\sigma$.

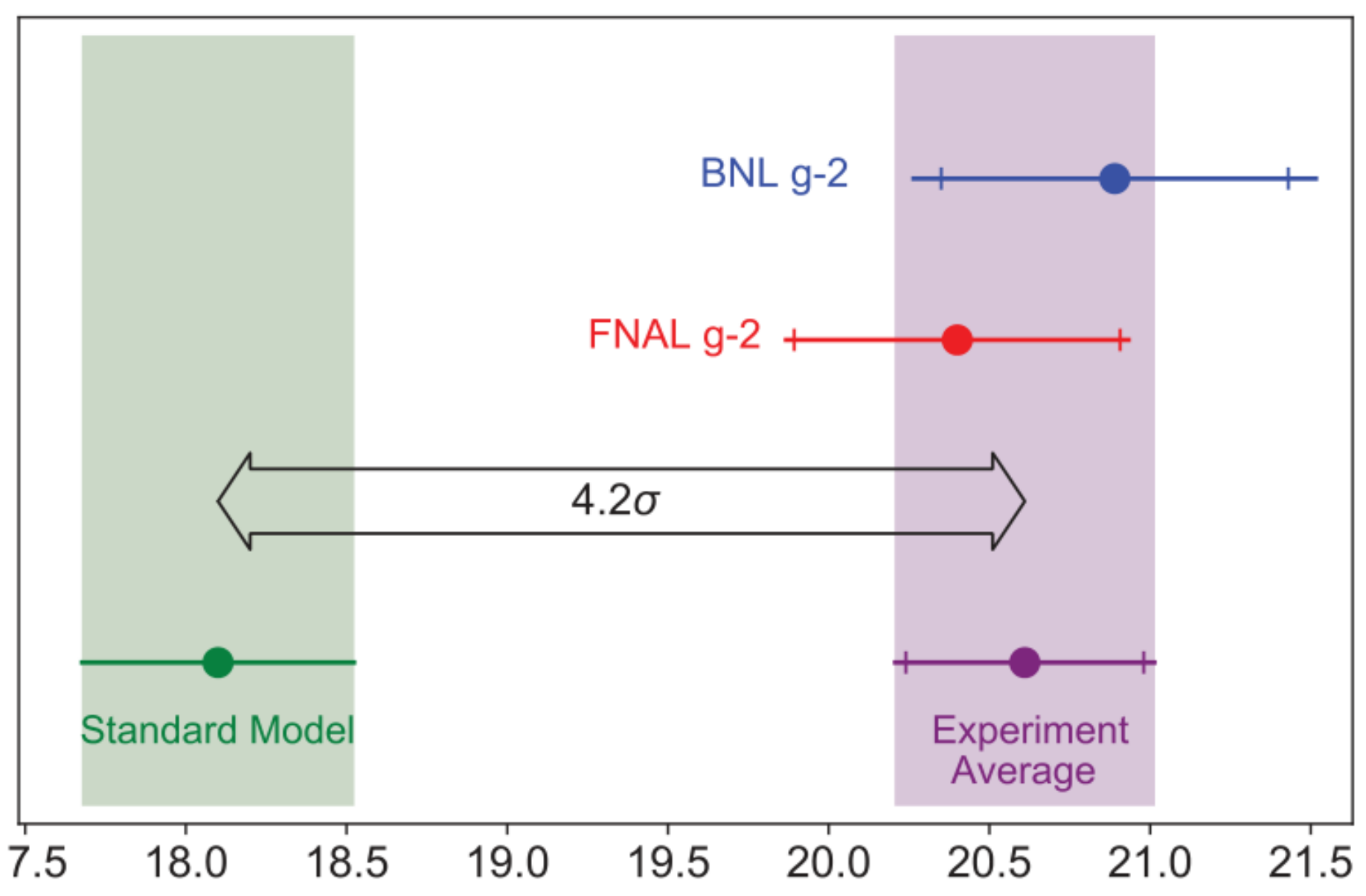

**Fig. 1:** Results of the Fermilab muon $g-2$ experiment, and combination with Brookhaven results. Scale is $10^{-10}$.

- The large discrepancy between the standard model and experimental values of $a_\mu$ motivates a beyond the standard model explanation of the anomaly.

## Muon $g-2$ Diagrams

- So how could introducing new particles from beyond the standard model explain the $a_\mu$ anomaly?
- $a_\mu$ corresponds to loop diagrams of the form:

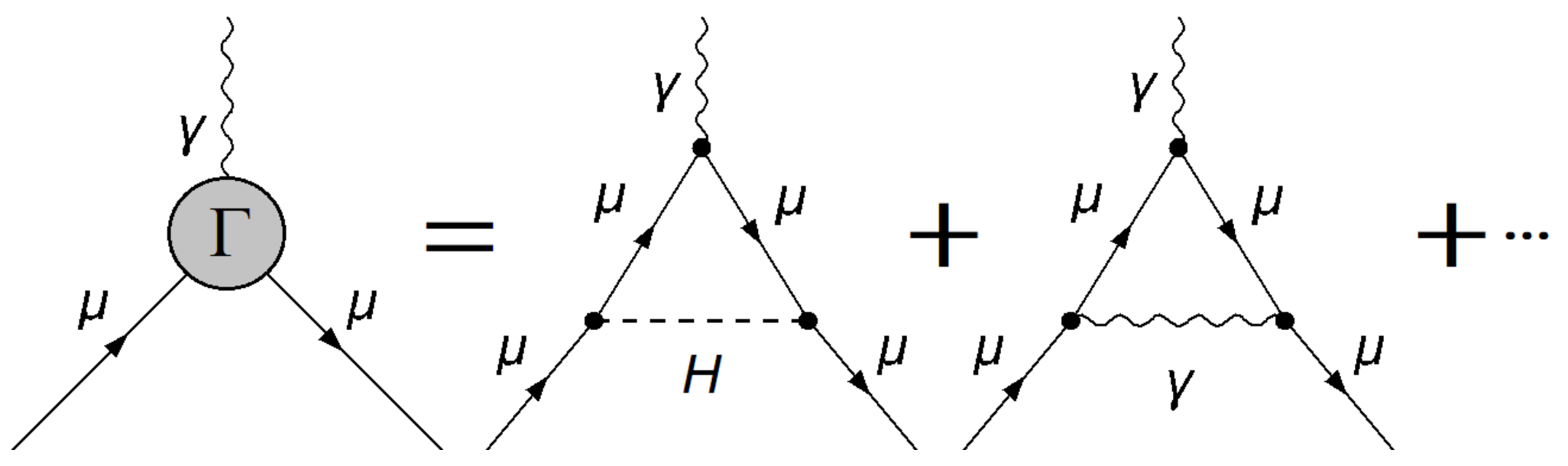

**Fig. 2:** Diagrams contributing to the value of $a_\mu$.

- Diagrams solely comprised of standard model particles (like the two above) combine to form $a_\mu^{\mathrm{SM}}$.
- If we extend the standard model with new particles, then diagrams involving loops with beyond the standard model particles could explain the discrepancy $\Delta a_\mu^{2021}$.

## Goals

We surveyed simple extensions of the standard model with the following goals in mind:

- Explain the size of the discrepancy $\Delta a_\mu^{2021}$ by introducing a single field, a pair of fields, or three fields.
- Examine which of these single, two, and three field models can explain $\Delta a_\mu^{2021}$ whilst avoiding constraints from collider searches.
- Provide a particle which is a viable candidate to be dark matter.

## Single Field Extensions

- In our above work, one can see that many single field extensions of the standard model are ruled out since they can only provide a negative contribution to $a_\mu$, while $\Delta a_\mu^{2021}$ is positive.
- Several vector leptoquarks are ruled out by ultraviolet completion problems.
- Finally, some of these single field extensions cannot produce a large enough contribution to explain $\Delta a_\mu^{2021}$ whilst avoiding collider constraints.
- This leaves us with only four possibilities for explaining $\Delta a_\mu^{2021}$ with a single field: The Two-Higgs Doublet Model, the leptoquarks $S_1$ and $R_2$, and in special cases, a dark photon or $Z$ boson. Let's look at one of the leptoquarks in more detail.

## Leptoquark $S_1$

By coupling the leptoquark $S_1$ to the muon and top quark we can explain the $a_\mu$ anomaly, whilst avoiding LHC and flavour constraints, as seen below.

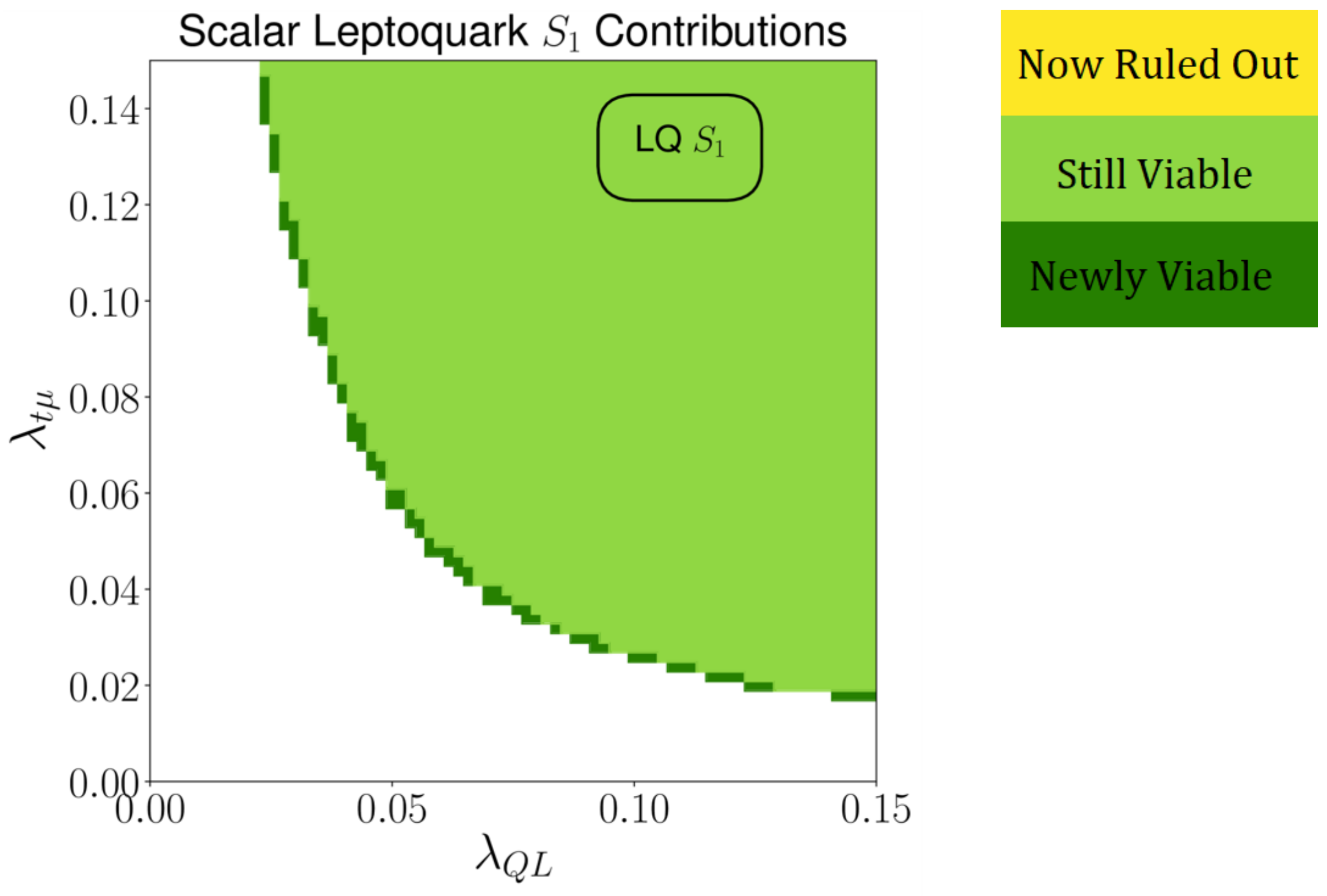

**Fig. 3:** Profile over the leptoquark mass in the plane of the couplings. The lime regions indicate the couplings which previously could and can still explain the $a_\mu$ anomaly within $1\sigma$ after the Fermilab results, and the green regions indicate couplings which can newly explain the $a_\mu$ anomaly within $1\sigma$. All points shown avoid LHC searches for leptoquarks.

## Two Field Extensions

- When introducing a pair of fields to explain the $a_\mu$ anomaly, we would also like to provide a candidate for dark matter. By introducing a $Z_2$ symmetry where under the symmetry all standard model particles are even and all new particles odd, then the lightest $Z_2$-odd particle is stable.
- Our above work reviews the ability of all two-fields of different spin to explain the $a_\mu$ anomaly.
- Again, many of these extensions are only able to produce a negative contribution to $a_\mu$.
- Other extensions are not able to produce a large enough contribution to $a_\mu$ whilst avoiding collider constraints.
- All of the remaining extensions in the above table are able to explain $\Delta a_\mu^{2021}$, but only with an under abundant dark matter relic density.
- Let's look at one of these models.

## Two Fields

If we couple a new fermion doublet with mass $M_\psi$ and neutral scalar singlet with mass $M_\phi$ to the muon, then we can explain the $a_\mu$ anomaly in the below plot.

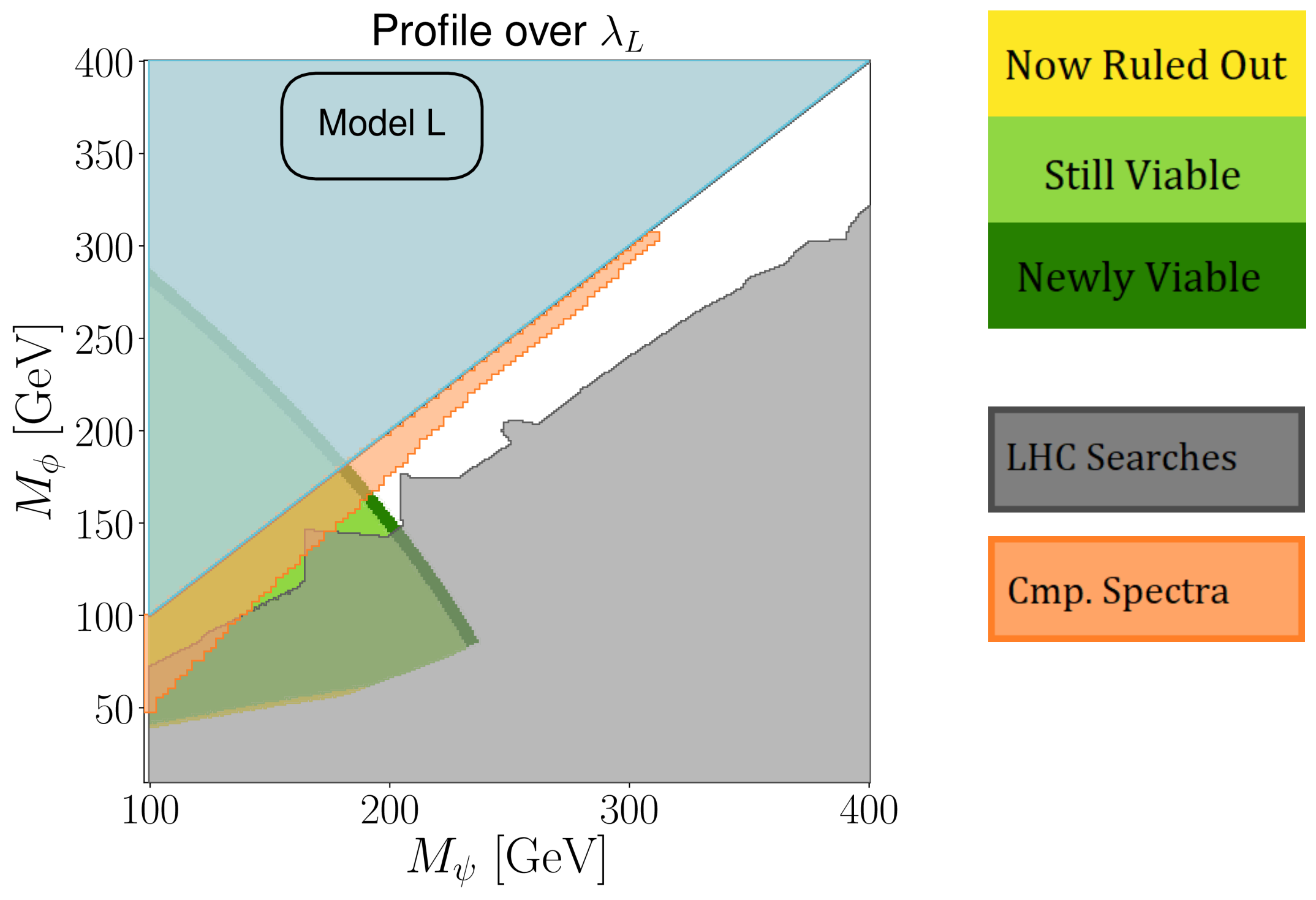

**Fig. 4:** Profile over the coupling $\lambda_L$ between the new fields and the muon. The neutral scalar singlet is the dark matter candidate in this model, and we exclude points where it has an over abundant dark matter relic density.

Whilte it is possible to explain the $a_\mu$ anomaly with the above two field extension of the standard model, however, it is only with an under abundant relic density. If we require the relic density to exactly match the Planck measured value, then it is only possible to explain $\Delta a_\mu^{2021}$ in regions ruled out by LHC searches. If we want to explain $\Delta a_\mu^{2021}$ and dark matter simultaneously, then we need at least three fields.

## Three Fields

A model which can simultaneously explain the $a_\mu$ anomaly whilst providing a suitable dark matter candidate is extension of the standard model introducing a scalar doublet, neutral scalar singlet, and charged fermion singlet, as seen below.

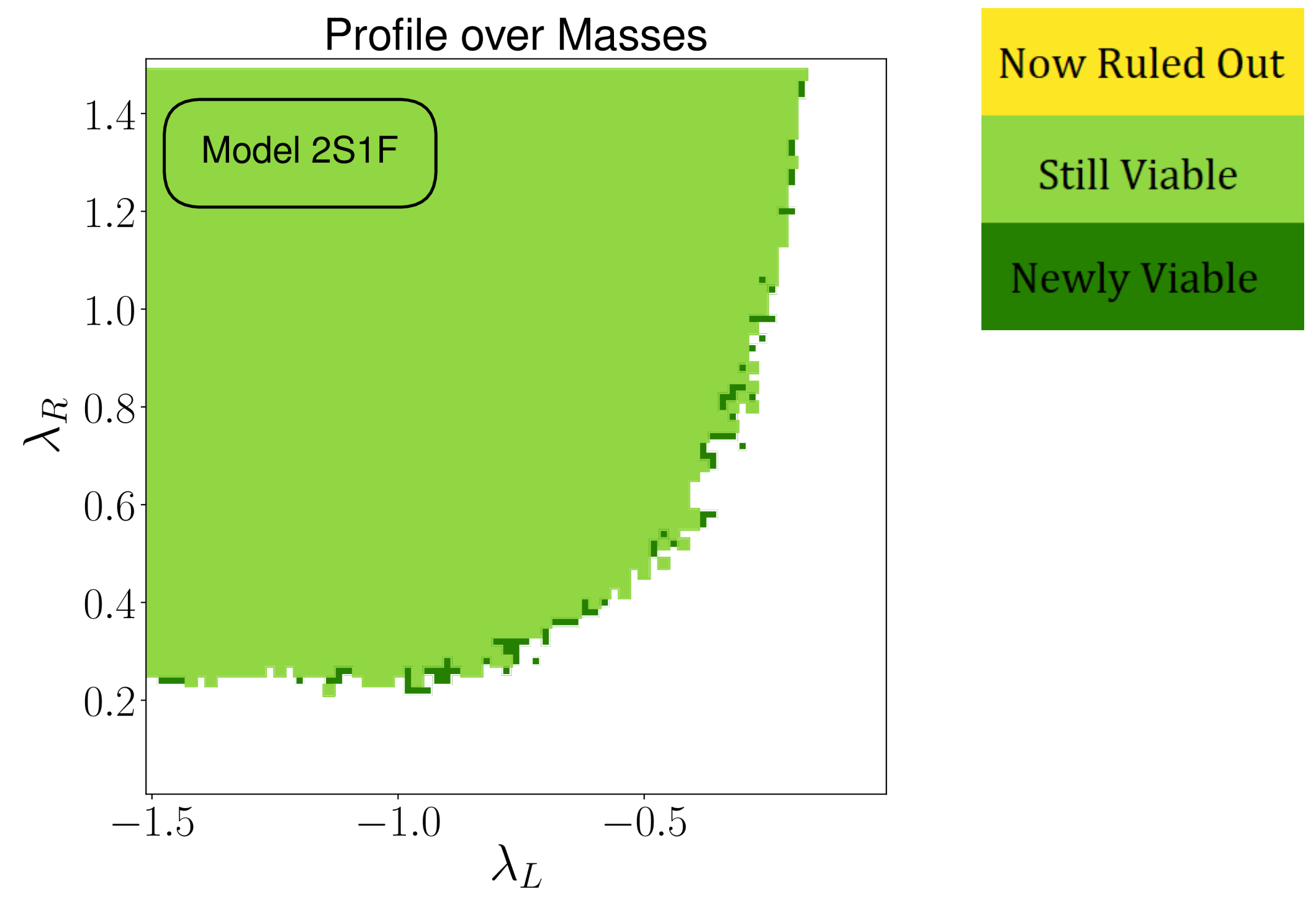

**Fig. 5:** Profile over the new field's masses and mixing couplings, in the plane of the muon's couplings to new fields. All points shown avoid LHC search constraints, direct detection searches, and provide a candidate for dark matter with an abundance which matches the Planck measurement.

## Supersymmetry

The three fields model we examine is closely related to the BLR (bino-left smuon-right smuon) contribution in the MSSM. In our work we cover the major contributions to $\Delta a_\mu$ find that it is possible to simultaneously explain the $\Delta a_\mu^{2021}$ anomaly in the MSSM whilst providing a Bino LSP which is a suitable dark matter candidate.