Expectations for the muon g-2 in simplified models with dark matter

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Based on:

K.Kowalska, EMS

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technische universität dortmund

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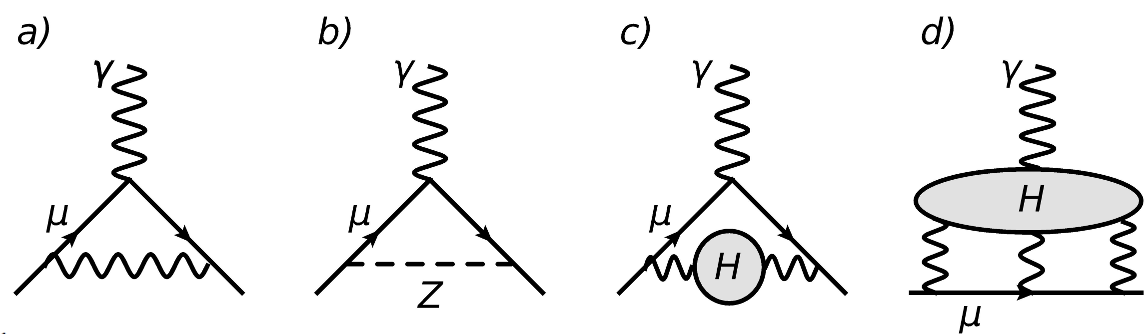
Muon g-2

- **Measured at Brookhaven:**

$$a_\mu^{\rm exp} = 116592089(63) \times 10^{-11}$$

Bennet *et al.*, hep-ex/0602035 (PRD 2006)



- **Discrepancy with SM:**

$$a_\mu^{\rm SM} = 116591802(49) \times 10^{-11}$$

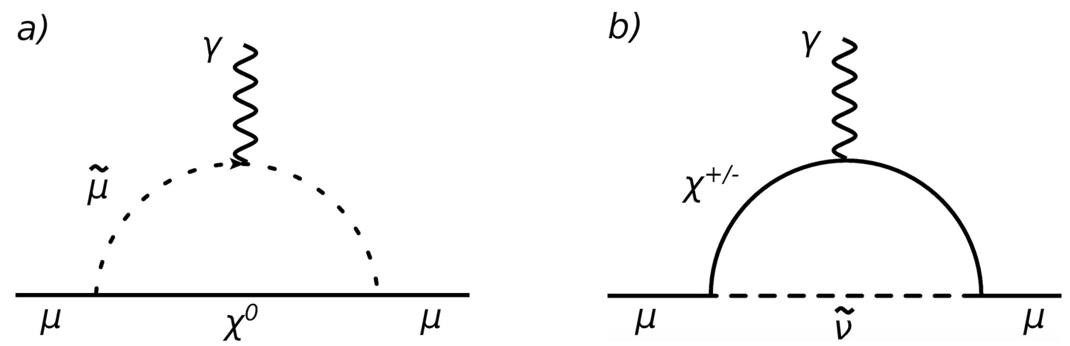
$$\delta\,(g-2)_\mu = (28.7 \pm 8.0) \times 10^{-10}$$

3.5 σ

New upcoming experiments will test the anomaly...
Fermilab, J-PARC, 7σ!!

Muon g-2

Explanations of the anomaly abundant in the literature...
e.g. SUSY:



Interesting assumption in MSSM:

Same BSM physics is responsible for $\delta(g-2)_\mu$ and $\Omega h^2 \approx 0.12$

(charginos, sleptons / neutralino DM)

We will apply the same assumption to generic frameworks...

Simplified models with dark matter approach to the muon g-2

- The dark matter interacts with the muons through renormalizable couplings
- Interactions are CP conserving and invariant under the SM gauge group, SU(2)×U(1)
- Each model satisfies the constraints from perturbativity and unitarity
- The measurement of the relic abundance is an active constraint on the parameter space.

Fermion-scalar-fermion:

$$\mathcal{L} = g_s\,\bar{\psi}_E \psi_\mu \phi_S + i g_p\,\bar{\psi}_E \gamma^5 \psi_\mu \phi_S + \text{h.c.}$$

This work!

Fermion-vector-fermion:

$$\mathcal{L} = g_v Z'_\nu \bar{\psi}_E \gamma^\nu \psi_\mu + g_a Z'_\nu \bar{\psi}_E \gamma^\nu \gamma^5 \psi_\mu + \text{h.c.}$$

MINIMAL ASSUMPTIONS:
Z_2 symmetry + vector-like new fermions

Investigated models

Models with a real neutral scalar SU(2) singlet

- Fermion SU(2) singlets
- Fermion SU(2) doublets
- Mixing singlet and doublet fermions

Models with a complex scalar SU(2) singlet

- Fermion SU(2) singlets
- Fermion SU(2) doublets
- Mixing singlet and doublet fermions

Models with an SU(2) scalar doublet

- Fermion SU(2) singlets
- Fermion SU(2) doublets
- Fermion SU(2) triplets
- Fermion adjoint triplets
- Mixing cases

Model 1: Scalar R singlet / fermion singlets

Lagrangian:

$$V = -\mu^2\phi^\dagger\phi + \frac{\lambda}{2}(\phi^\dagger\phi)^2 + \frac{\mu_s^2}{2}s^2 + \frac{\lambda_s}{2}s^4 + \lambda_{12}s^2\phi^\dagger\phi$$

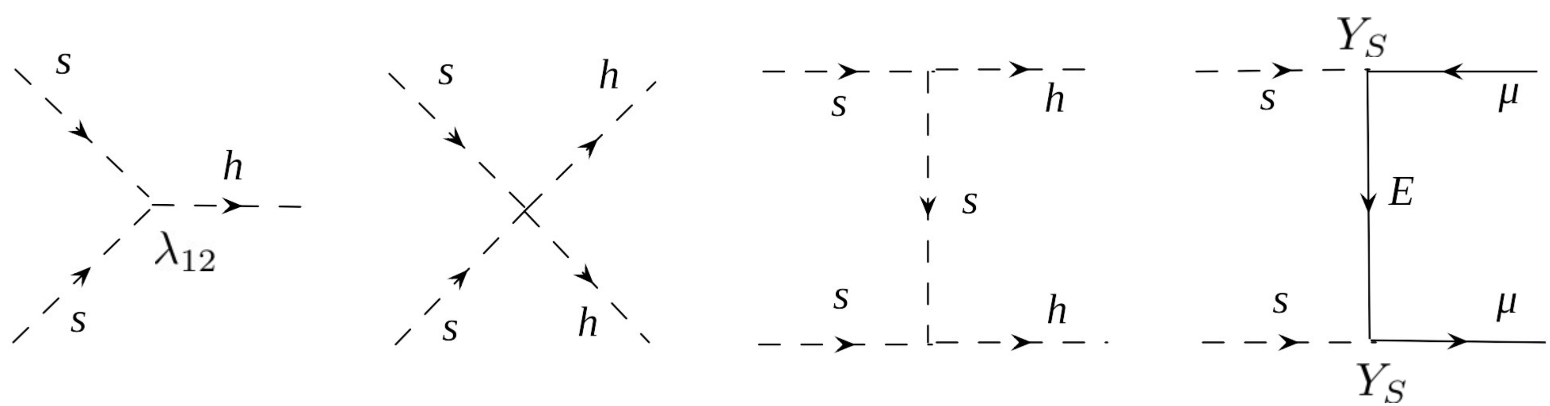
(s inert field, ϕ SM Higgs)

$$\mathcal{L} \supset -Y_S\, E\, e_R^* s - M_E E' E + \text{h.c.}$$

VL heavy lepton

muon

Relic abundance can be easily obtained:



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VL heavy lepton

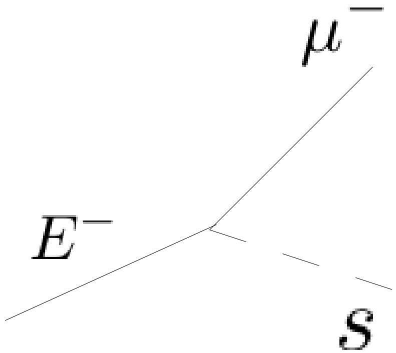
muon

Muon g-2 contributions:

$$\delta\,(g-2)_\mu = \frac{1}{16\pi^2}\sum_{S^0,E^\pm}\left[\frac{m_\mu^2}{m_S^2}\left(\cancel{|c_L|^2} + \underline{|c_R|^2}\right)\mathcal{F}_1(r) + 2\,\frac{m_\mu m_E}{m_S^2}\,\cancel{\Re(c_L c_R^*)}\,\mathcal{F}_2(r)\right]$$

Only piece in Model 1

Constraints

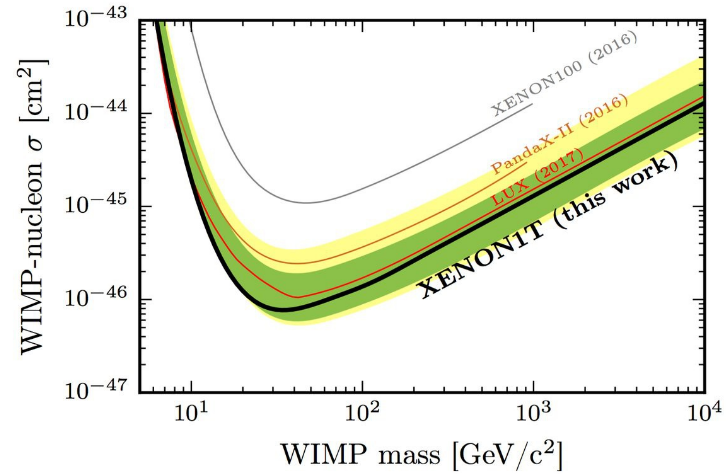


ATLAS, CMS: 2 lepton + missing E_T

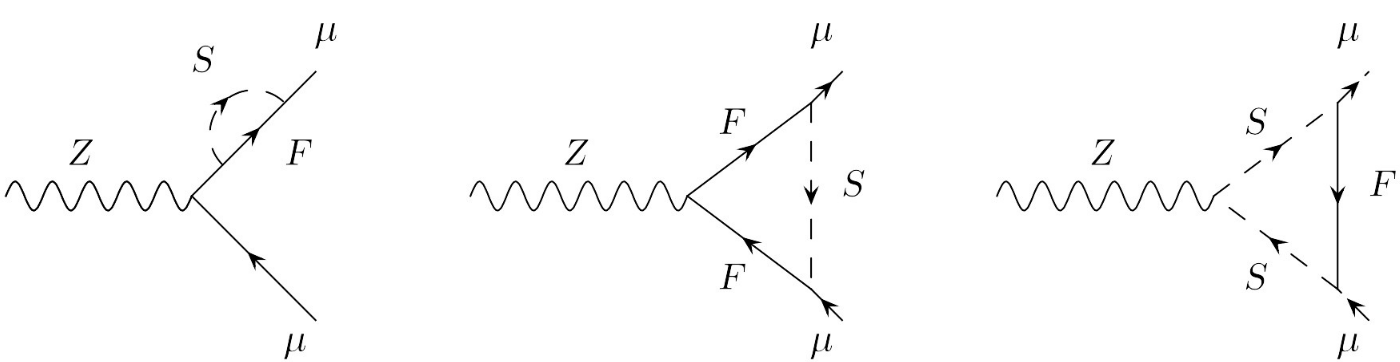
Mono-jet

MadGraph, PYTHIA, DELPHES3

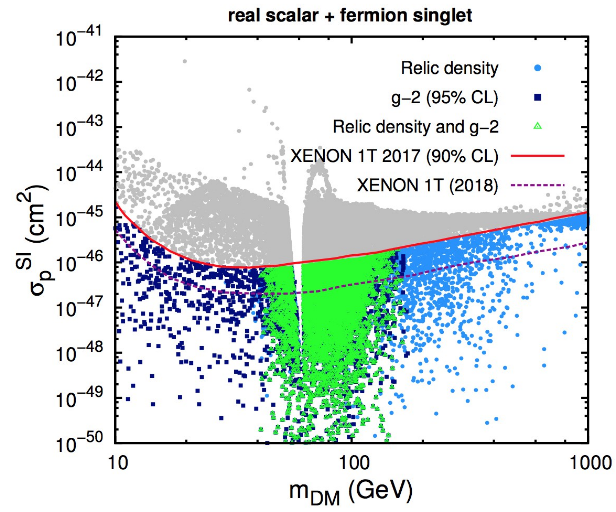
DIRECT DM SEARCHES:

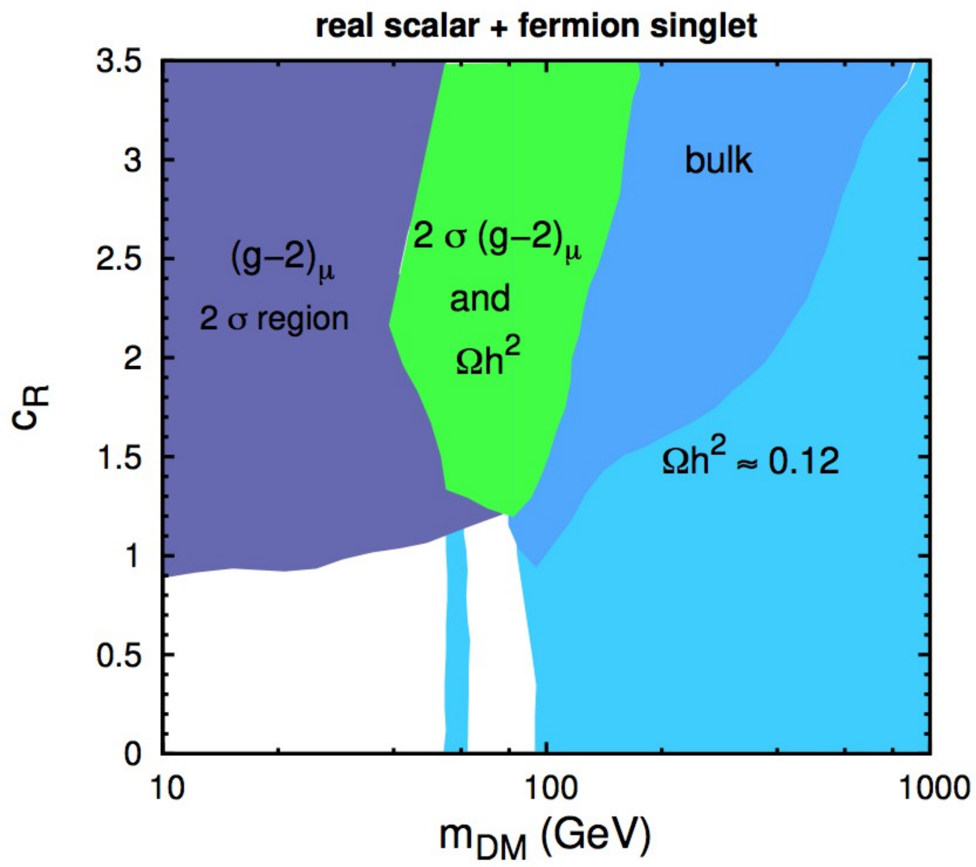


PRECISION TESTS at LEP:



Model 1 results

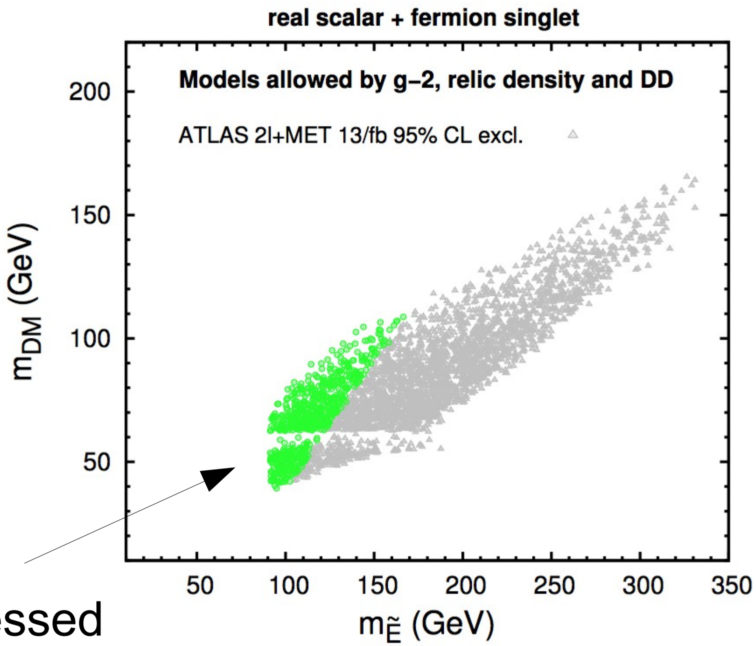


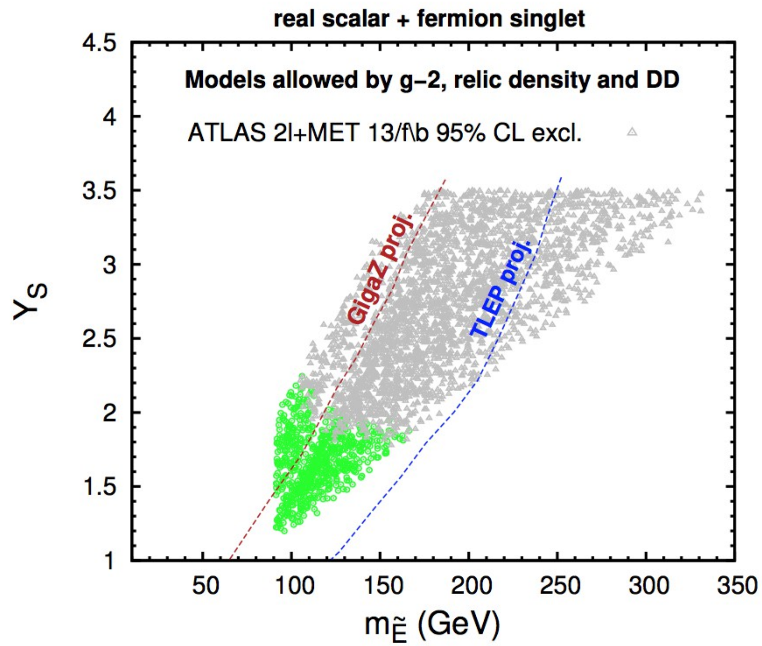


- **New Yukawa** $Y_S > 1 - 1.5$
- ***m_{DM}* range:** 40 GeV – 180 GeV
- **DM dominant mechanism:** *t*-channel fermion exchange

Model 1 results

AFTER LHC CONSTRAINTS:

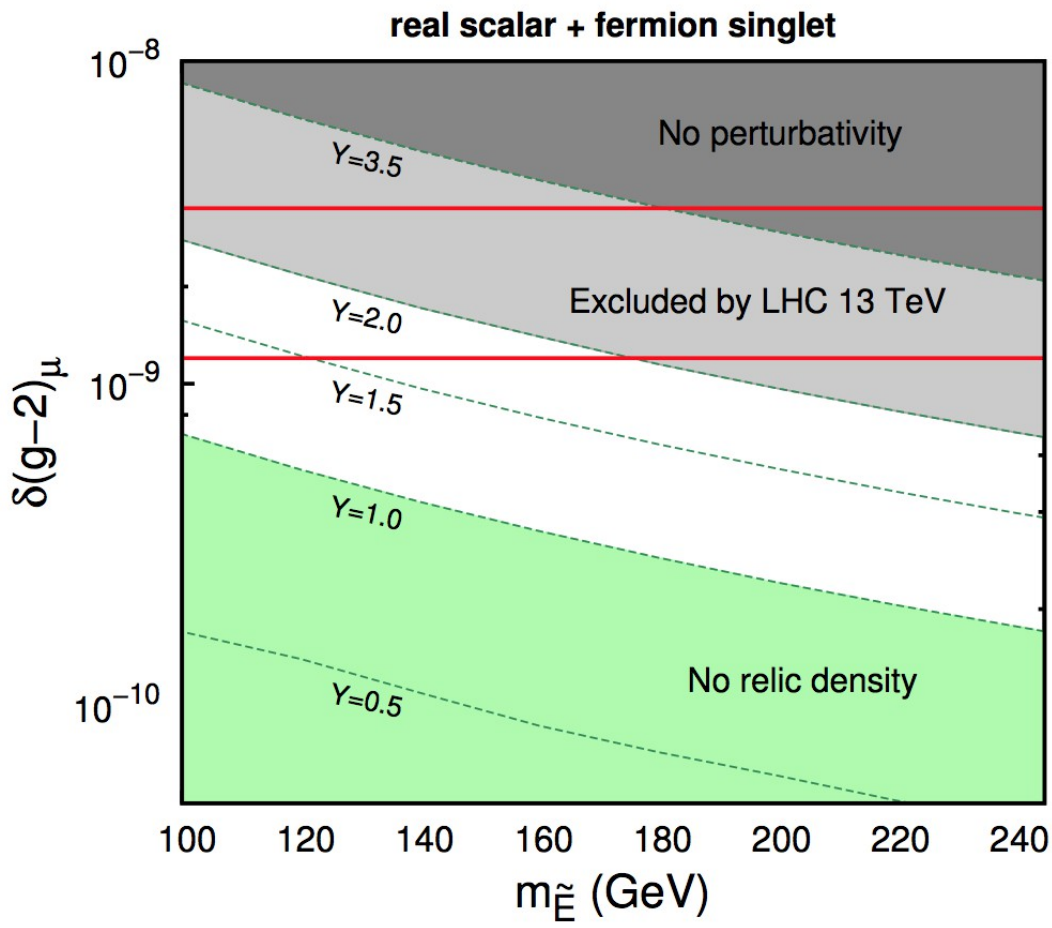




Compressed
Region survives

Surviving parameter space tested by future precision experiments GigaZ, TLEP

Model 1 results

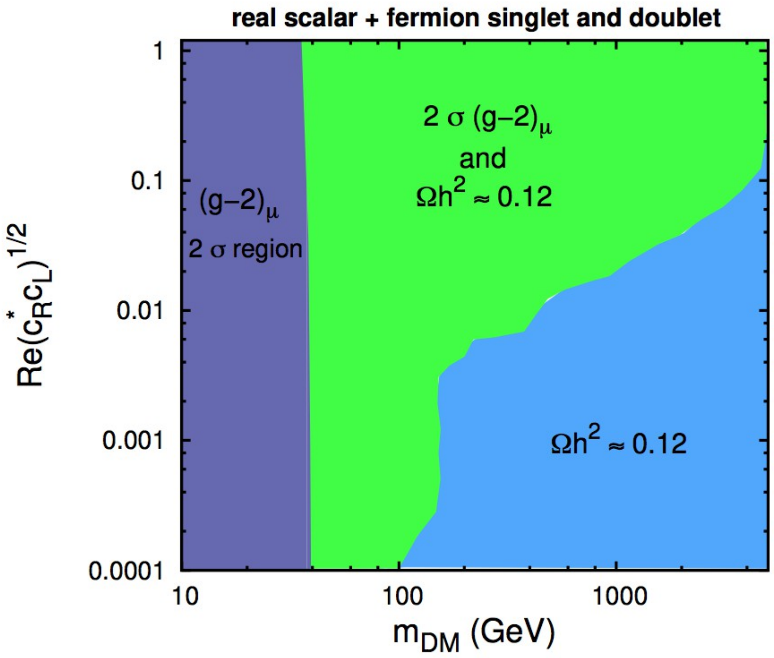


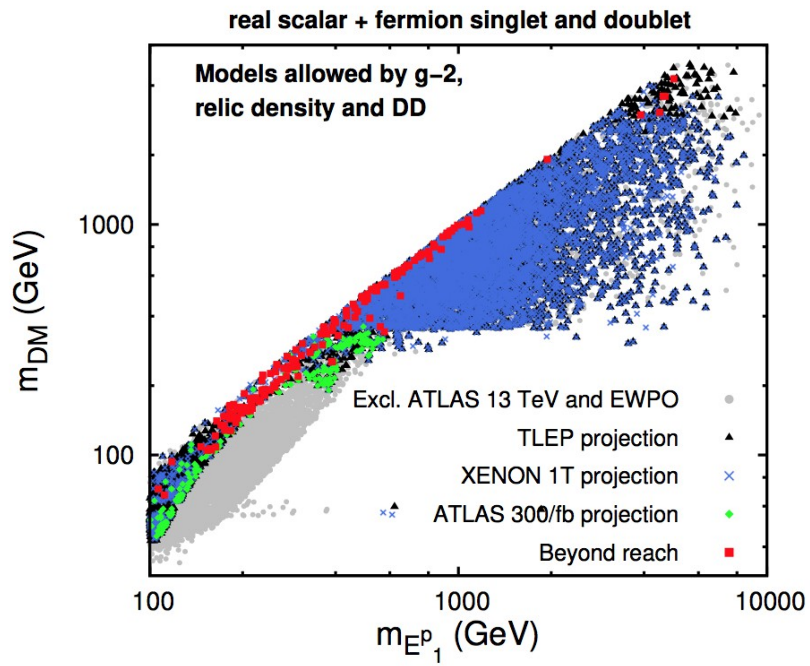
Predictive: interplay of bounds from LHC and the relic density

Mixing singlet/doublet fermions

$$\delta\left(g-2\right)_\mu = \frac{1}{16\pi^2}\sum_{S^0,E^\pm}\left[\frac{m_\mu^2}{m_S^2}\left(|c_L|^2+|c_R|^2\right)\mathcal{F}_1(r) + 2\,\frac{m_\mu m_E}{m_S^2}\,\Re(c_L c_R^*)\,\mathcal{F}_2(r)\right]$$

g-2 boost





- **Large mass range allowed**
- **Tested by combination of LHC, PRECISION, DM DIRECT DETECTION**

Scalar SU(2) doublet cases

Each case differs:

F singlet:

$$\mathcal{L} \supset -Y_S \left(\nu_L S^- E' + e_L \frac{S^{0*} E'}{\sqrt{2}} \right)$$

F doublet:

$$\mathcal{L} \supset -Y_D \left(N_1 S^- e_R^* + \frac{E_1 S^{0*}}{\sqrt{2}} e_R^* \right) + \text{h.c.}$$

(charged scalar contribution)

F triplet:

$$\mathcal{L} \supset -Y_T \left(\frac{\Psi^+ S^{0*}}{2} + \Psi^{++} S^- \right) e_L - Y_T \left(\frac{\Psi^0 S^{0*}}{\sqrt{2}} + \frac{\Psi^+ S^-}{\sqrt{2}} \right) \nu_L + \text{h.c.}$$

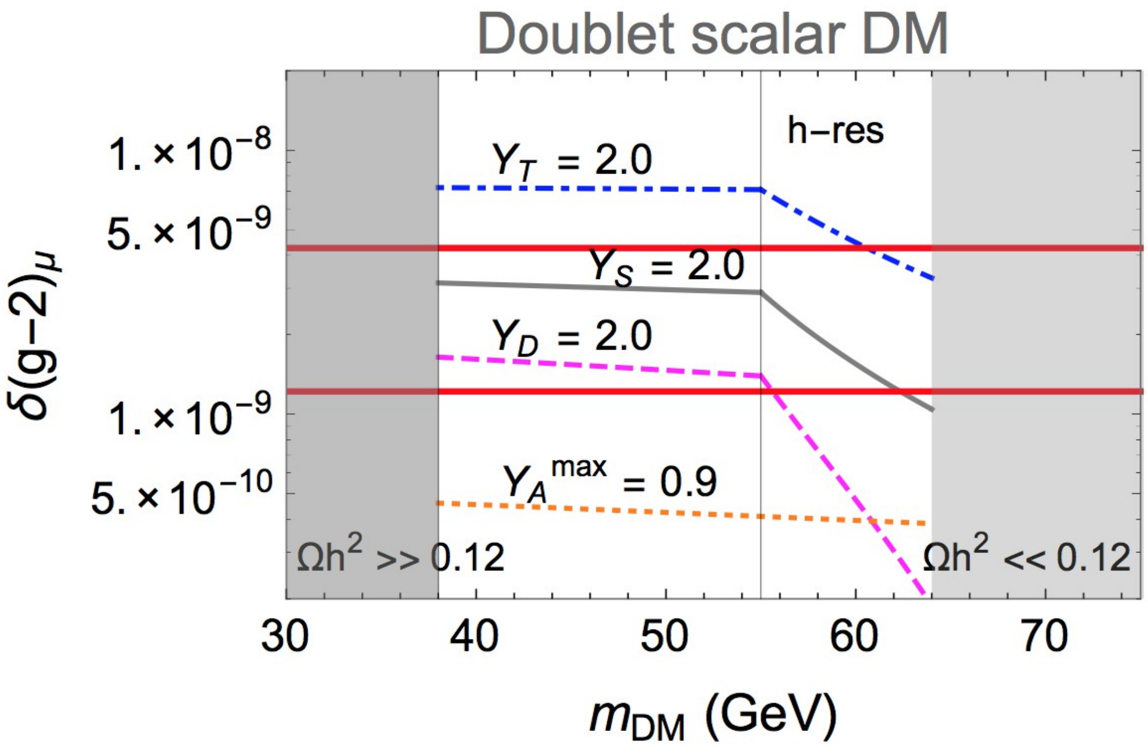
(Doubly charged fermion contribution)

F adjoint triplet:

$$\mathcal{L} \supset -Y_A \left(\frac{\Psi^0 S^+}{\sqrt{2}} + \frac{\Psi^+ S^0}{\sqrt{2}} \right) e_L - Y_A \left(\frac{\Psi^0 S^0}{2} - \Psi^- S^+ \right) \nu_L + \text{h.c.}$$

(Majorana fermions)

Scalar SU(2) doublet cases

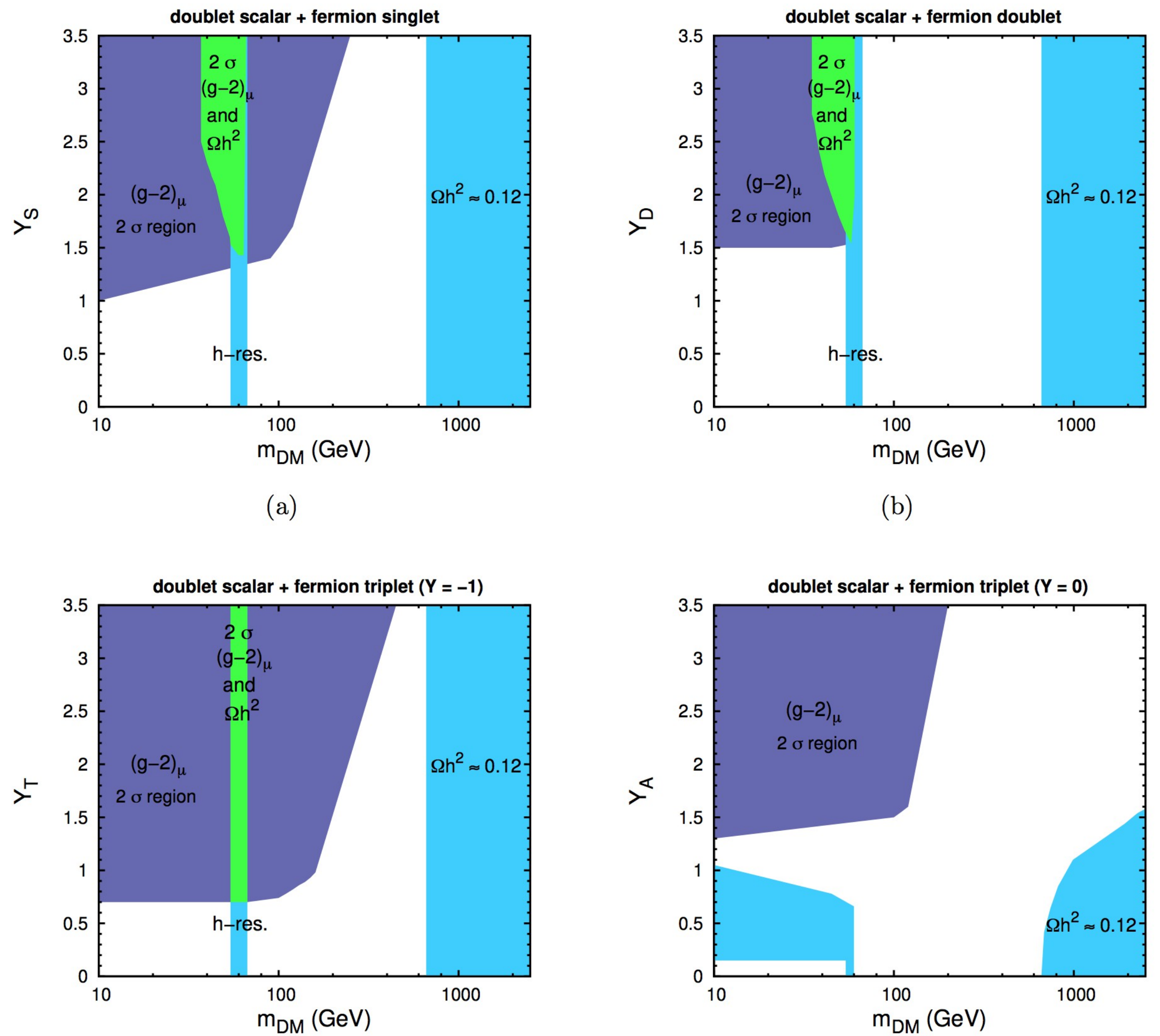


Connection g-2 / DM relic abundance:

- **F triplet fits BLN only <u>in</u> Higgs resonance**
- **F doublet fits only <u>outside</u> of Higgs resonance**
- **F adjoint triplet does not fit BLN**

Scalar SU(2) doublet cases

Favored parameter space differs in each case:



Summary

- Test hypothesis that, if g-2 is confirmed, the same physics is subject to $\Omega h^2 \sim 0.12$.
- Renormalizable SU(2) X U(1) invariant extensions of the SM with different gauge structure
- LHC and precision tests strongly constrain the p.s., and make some if these models stand out from one another
- If g-2 confirmed, new $e^+ e^-$ collider can probe even minimal models