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Theoretical overview of novel BSM models

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Motivation of the talk…

Dark Matter models testable at collider:

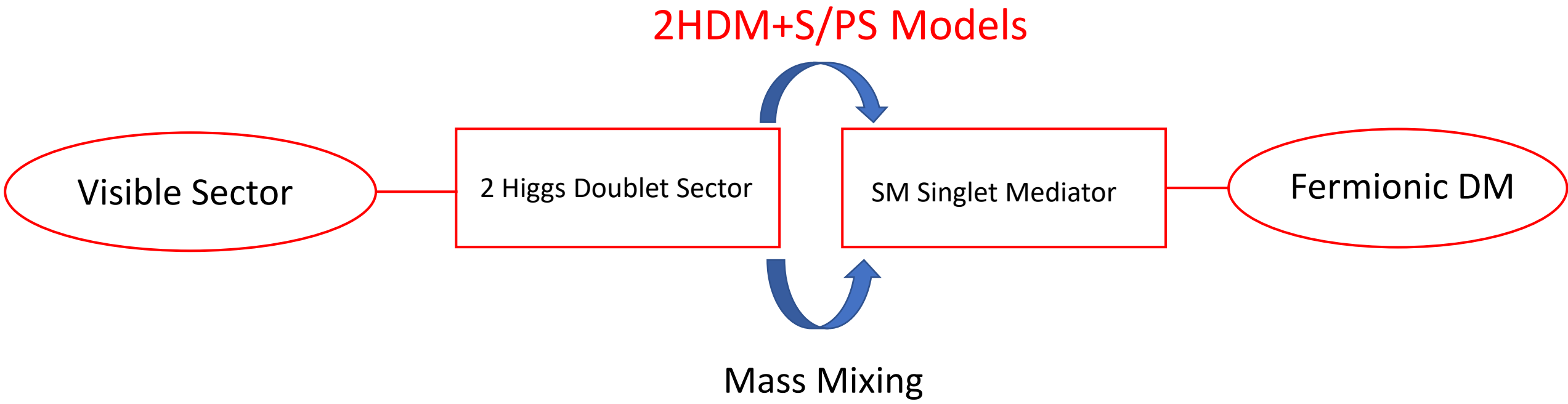
Good compromise between realistic model and a simplified predictive scenario.

Broad variety of collider signatures. E.g. light/heavy resonances, mono-X

Interesting DM phenomenology.

Disclaimer: Summary of selected models

First class of models:



$$V_S(S) = \frac{1}{2}M_{SS}^2 S^2 + \frac{1}{3}\mu_S S^3 + \frac{1}{4}\lambda_S S^4$$

Conventional 2HDM Potential

$$V_{S,2HDM}(\Phi_1, \Phi_2, S) = \mu_{11S}(\Phi_1\Phi_1^\dagger)S + \mu_{22S}(\Phi_2\Phi_2^\dagger)S + (\mu_{12S}\Phi_1\Phi_2^\dagger S + h.c.) + \frac{\lambda_{11S}}{2}(\Phi_1\Phi_1^\dagger)S^2 + \frac{\lambda_{22S}}{2}(\Phi_2\Phi_2^\dagger)S^2 + \frac{1}{2}(\lambda_{12S}\Phi_1\Phi_2^\dagger S^2 + h.c.)$$

$$V(\Phi_1, \Phi_2, S/P) = V_{2HDM}(\Phi_1, \Phi_2) + V_{self}(S/P) + V_{S/P,2HDM}(\Phi_1, \Phi_2, S/P)$$

Self Interaction lagrangian

$$V_P(P) = \frac{1}{2}M_{PP}^2 P^2 + \frac{1}{4}\lambda_P P^4$$

Singlet Doublet Interaction Lagrangian

$$V_{P,2HDM}(P) = \frac{\lambda_{11P}}{2}(\Phi_1\Phi_1^\dagger)P^2 + \frac{\lambda_{22P}}{2}(\Phi_2\Phi_2^\dagger)P^2 + \mu_{12P}P(i\Phi_1^\dagger\Phi_2 + h.c.)$$

EW Symmetry Breaking

$\langle \Phi_1 \rangle = v_1$

$\langle \Phi_2 \rangle = v_2$

$\frac{v_2}{v_1} = tan\beta$

2HDM+S

$(\Phi_1, \Phi_2, S) \longrightarrow (h, S_1, S_2, A, H^{\pm})$

2HDM+PS

$(\Phi_1, \Phi_2, P) \longrightarrow (h, a, H, A, H^{\pm})$

$L_{S,DM} = -y_\chi^S S \bar{\chi}\chi \longrightarrow -y_\chi^S (\sin\theta S_1 + cos\theta S_2)\bar{\chi}\chi$

$L_{P,DM} = -y_\chi^P P \bar{\chi}\chi \longrightarrow -y_\chi^P (sin\theta A + cos\theta a)\bar{\chi}\chi$

Dark Matter Phenomenology

2HDM+S

N. Bell, G. Busoni, I. W. Sanderson; JCAP 08 (2018) 017

Relic Density

P-wave dominated annihilation cross-section.

Direct Detection

Sizable (tree-level) Spin Independent DM/nucleon cross-section.

$$\sigma_{\chi p}^{SI} \propto \frac{y_\chi^2}{v^2} \sin^2\theta \cos^2\theta \left(\frac{1}{M_{S_1}^2} - \frac{1}{M_{S_2}^2} \right)^2$$

2HDM+PS

G.A. et al; JCAP 03 (2018) 042
F. Ertas and F. Kahlhoefer; JHEP 06 (2019) 052
T. Abe, M. Fujiwara and J. Hisano, JHEP 02 (2019)

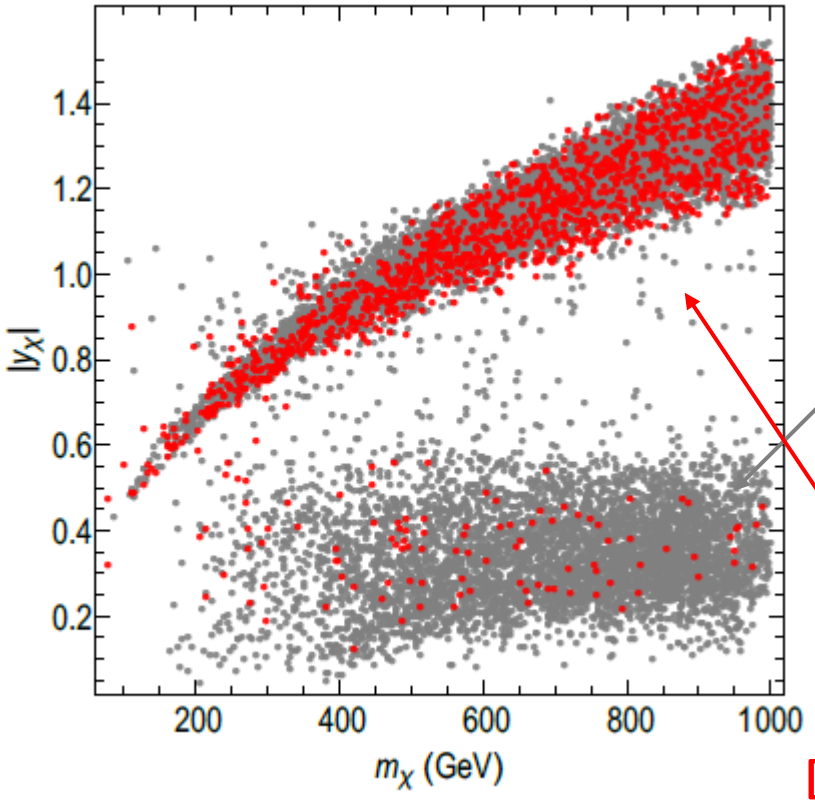
Relic Density

S-wave dominated annihilation cross-section.

Direct Detection

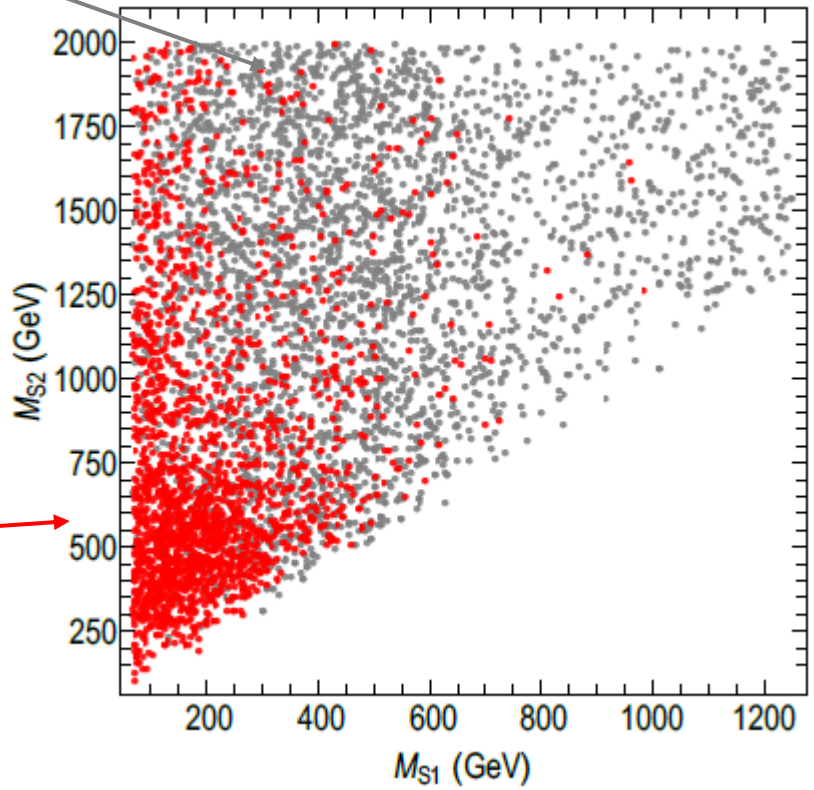
Very suppressed (Spin Dependent-like) tree level cross-section. SI cross induced at the loop level (can be probed by next generation detectors)

2HDM+S Model



DD Allowed

DD Ruled-out



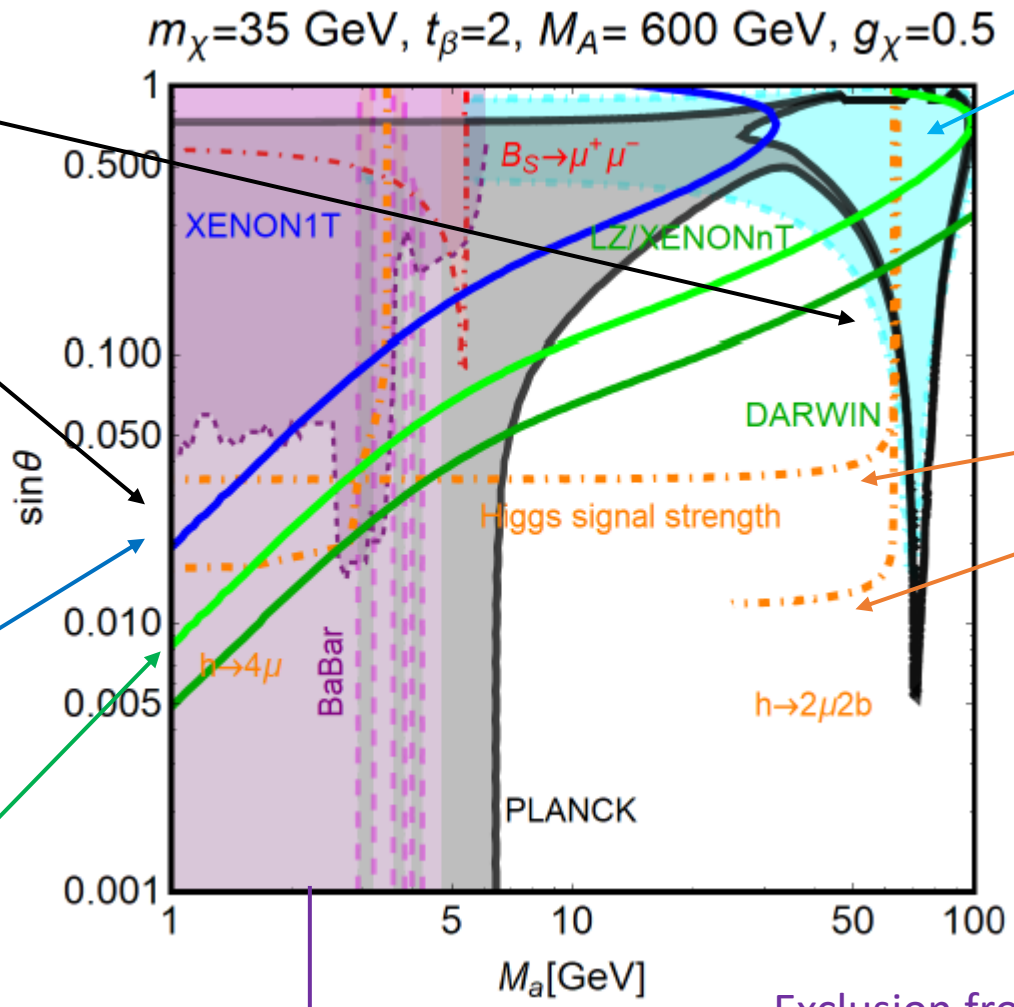
N. F. Bell, G. Busoni, I. W. Sanderson JCAP 01 (2018) 015

G.A., F.S. Queiroz, M. Lindner, W. Rodejohann, S. Vogl; JCAP 03 (2018) 042

Relic Density:Efficient annihilation into aa or $\bar{f}f$ final states

Exclusion from Indirect Detection

Personal contribution:
Numerical code for DM Direct Detection and relic density



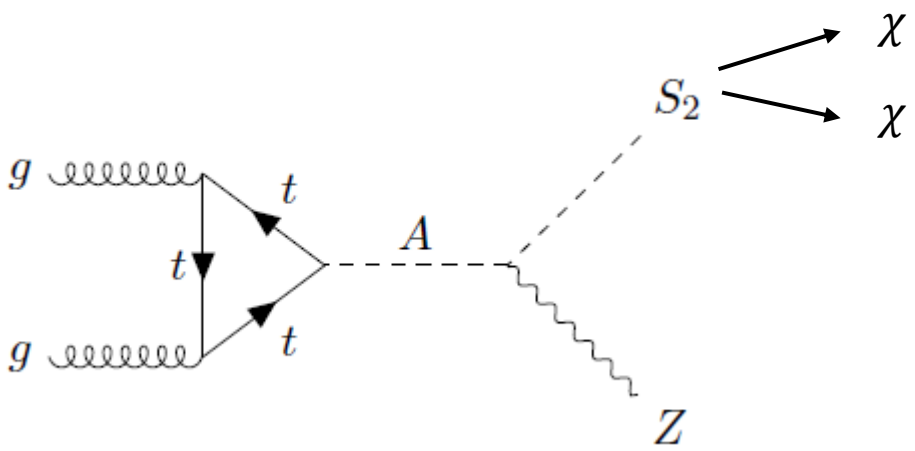
Higgs exotic decays

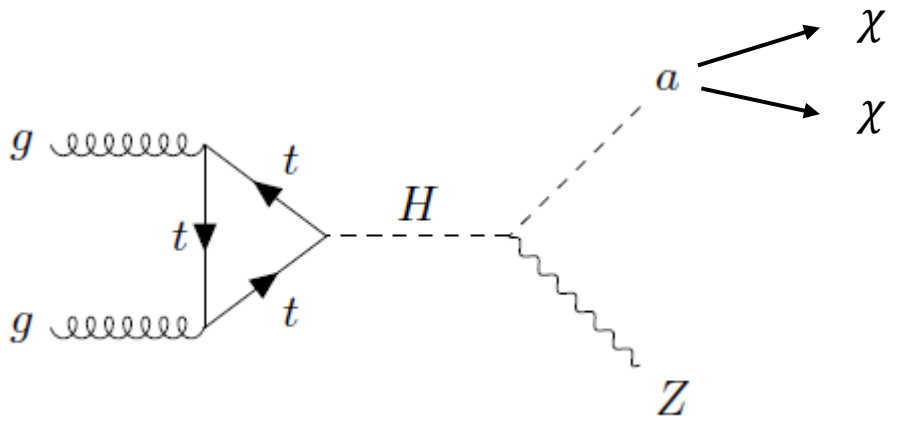
Direct Detection: Spin Independent interactions arise only at one-loop. Next generation detectors can nevertheless provide strong bounds.

Exclusion from low energy processes, e.g. meson decays

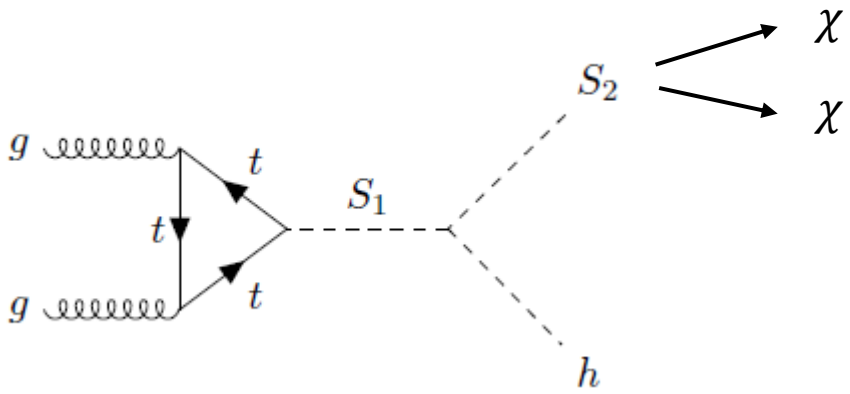
Purpouse of our Study: Can Mono-Z, Mono-h, $\bar{t}t$ signatures probe and possibly discriminate between 2HDM+S/2HDM+PS.

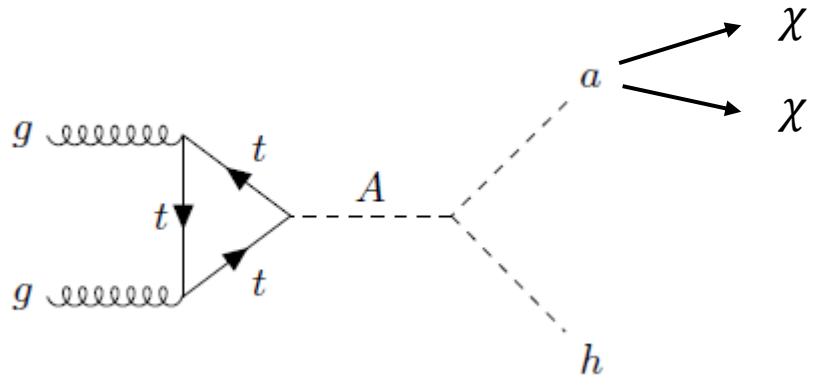
Mono-Z





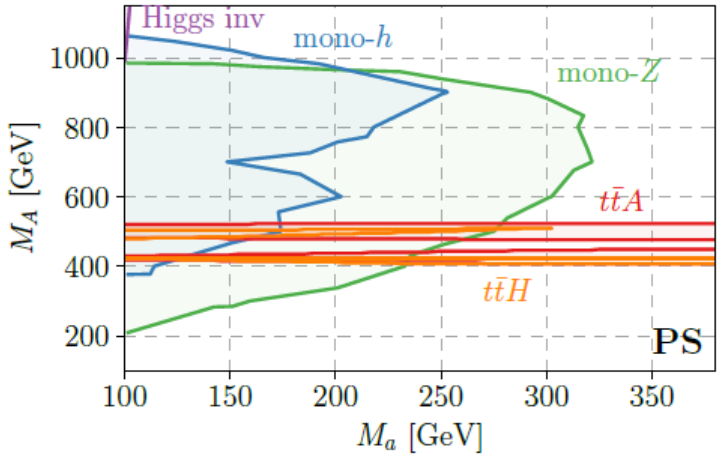
Mono-h

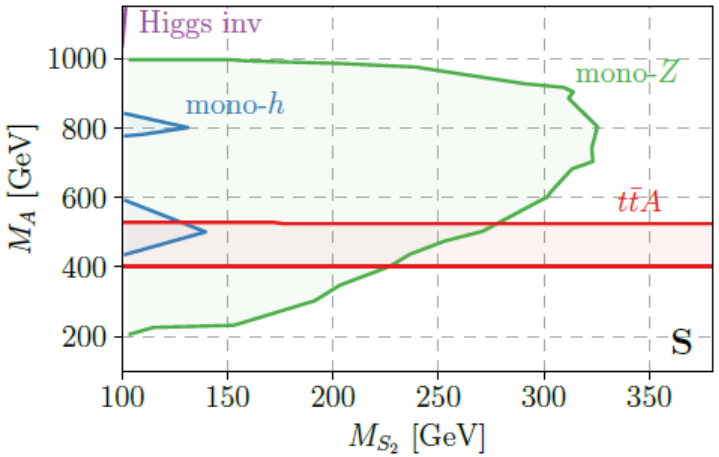


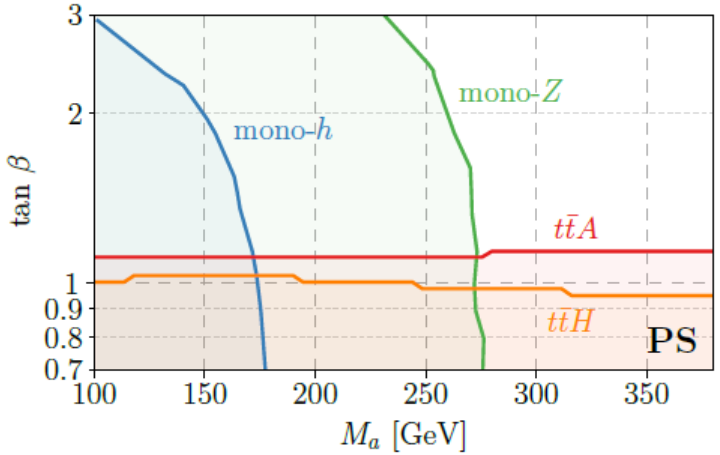


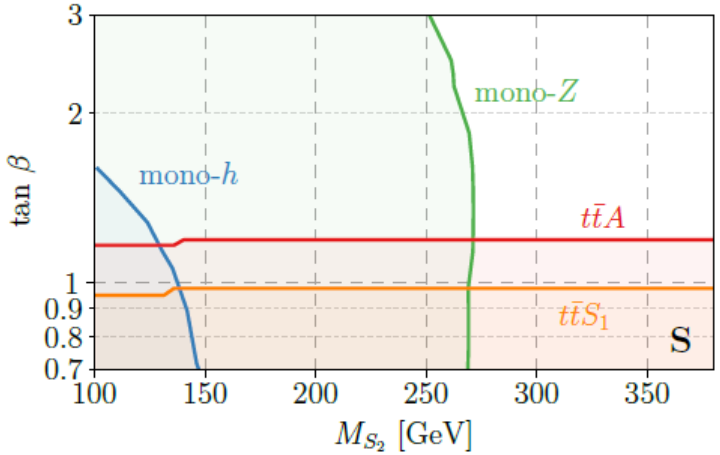
Summary of Combined Constraints

G.A., G. Busoni, T. Hugle, V. Tenorth *JHEP* 06 (2020) 098, see also T. Robens *Symmetry* 13 (2021) 12, 2341

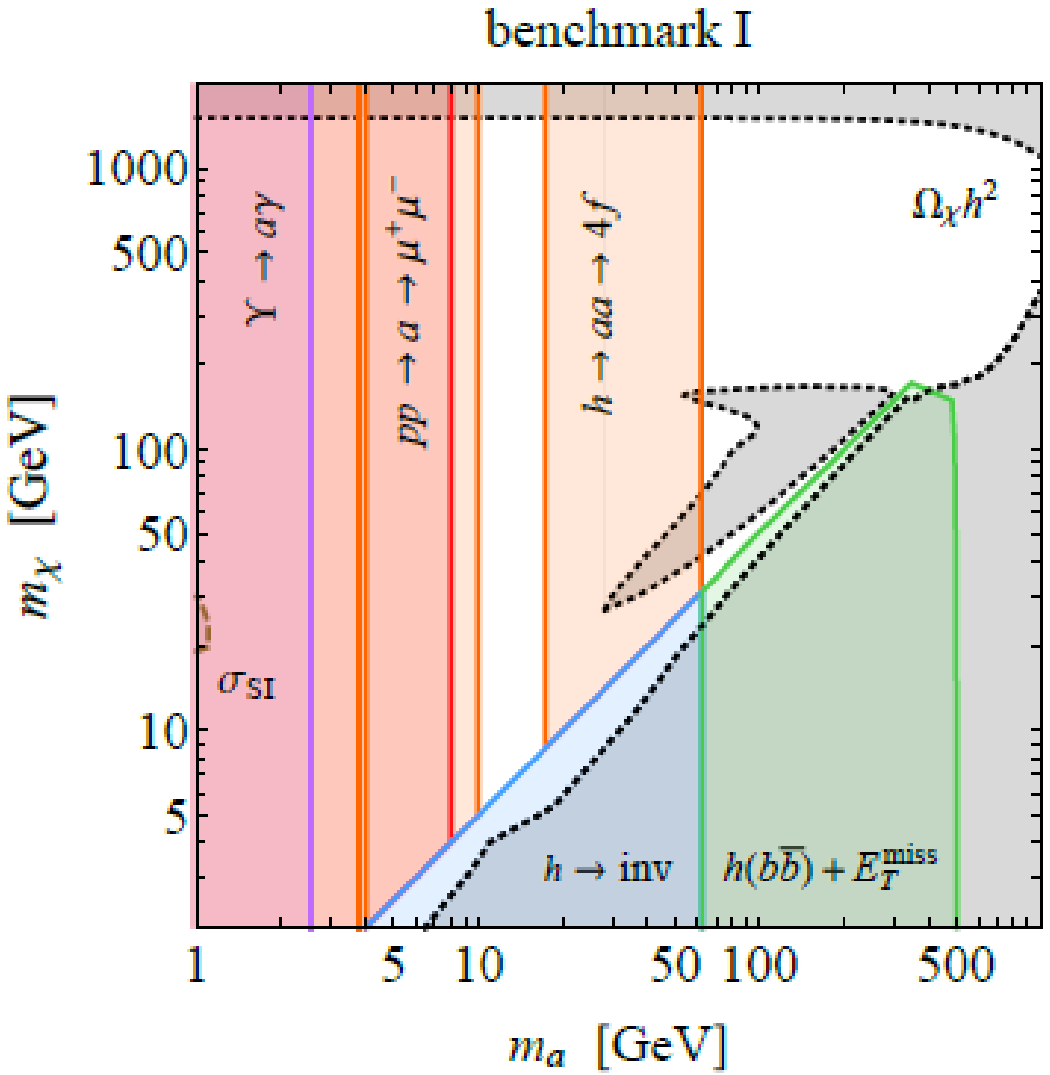








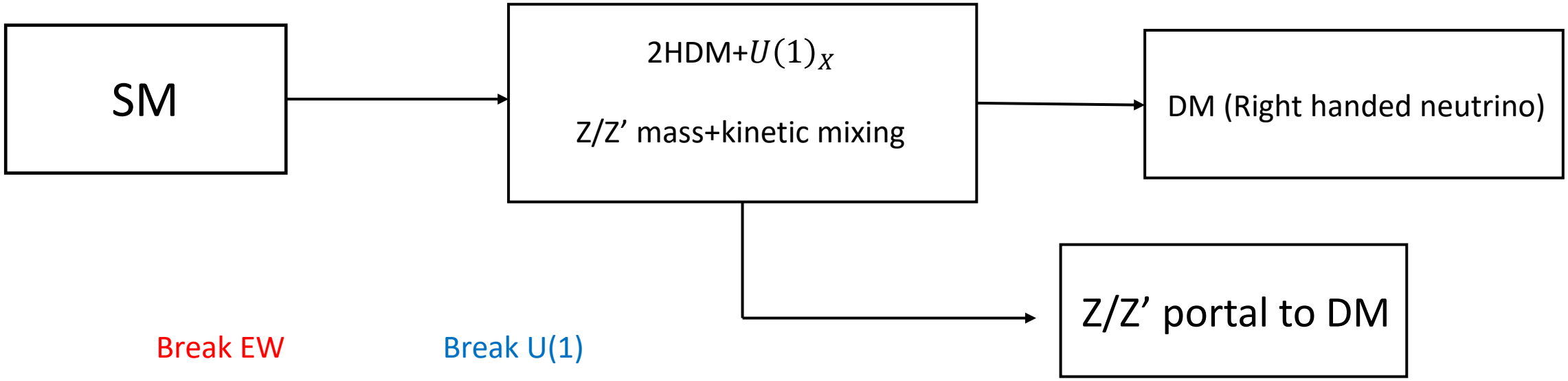
Sensitivity to searches of light resonances



S. Argyropoulos and U. Haisch arXiv:2202.12631

Second class of models:

2HDM+$U(1)_X$

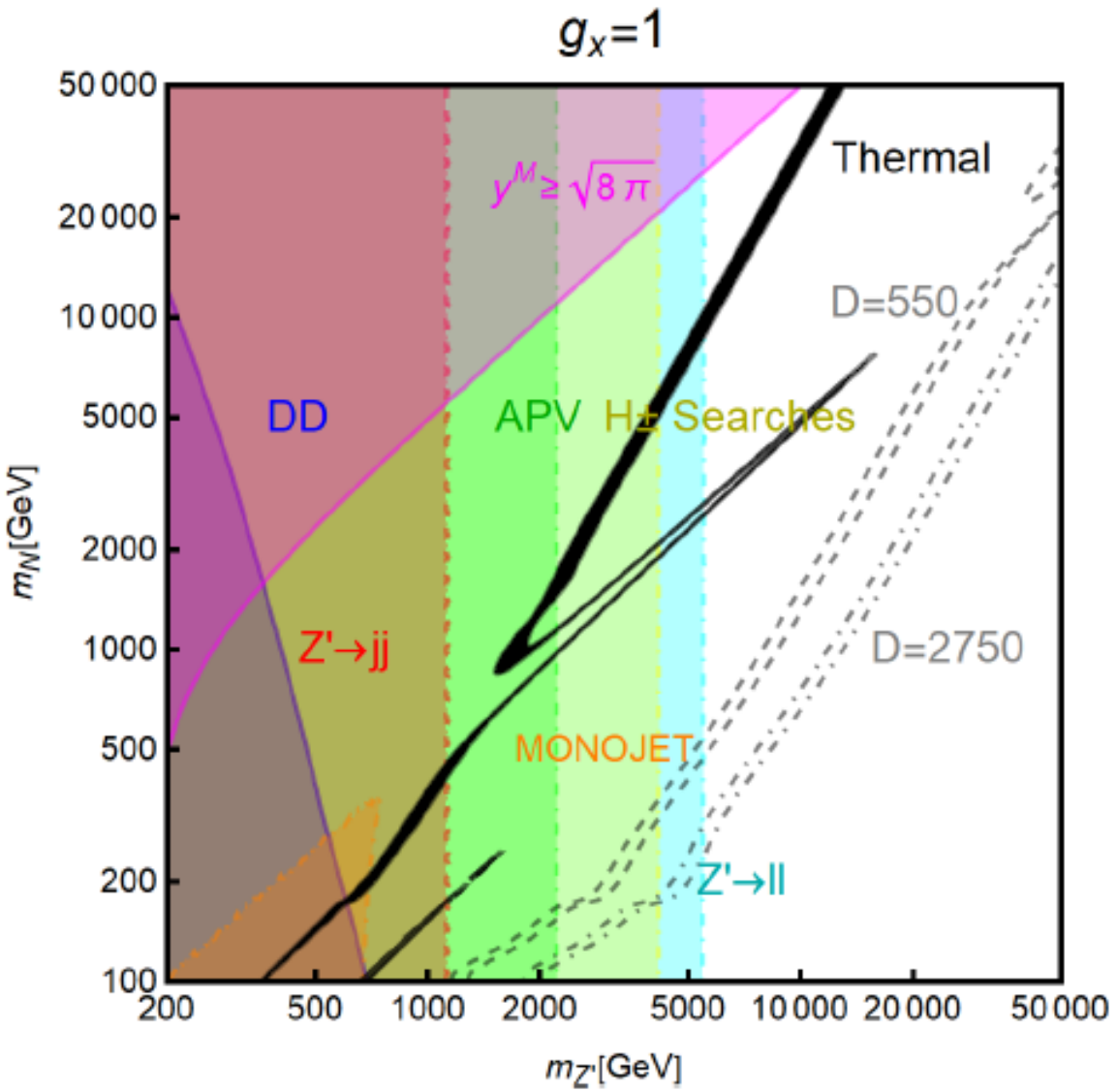


Break EW

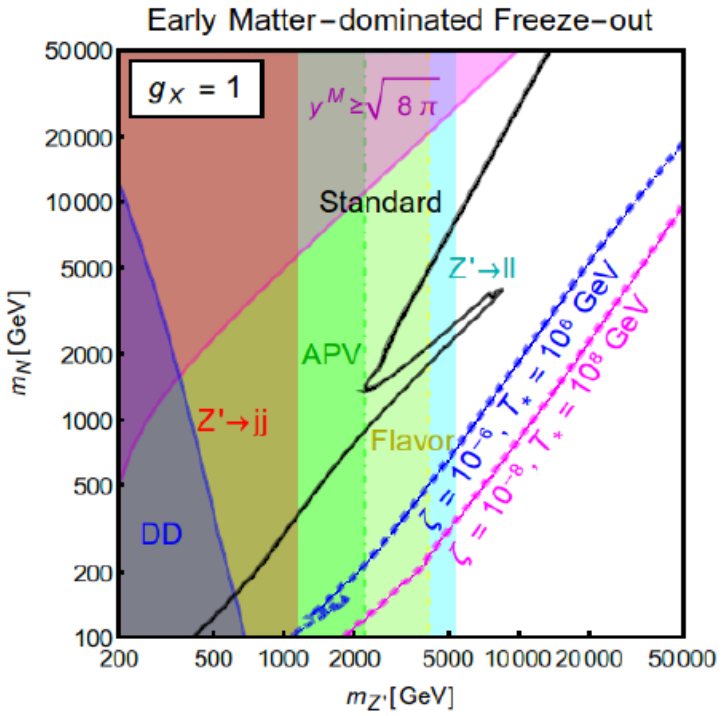
Break U(1)

$$\mathcal{L} = (D^\mu \phi_1)^\dagger (D_\mu \phi_1) + (D^\mu \phi_2)^\dagger (D_\mu \phi_2) + (D^\mu \phi_s)^\dagger (D_\mu \phi_s) =$$
$$+ \frac{1}{4} g^2 v^2 W^{-\mu} W^+_\mu + \frac{1}{8} g_Z^2 v^2 Z^{0\mu} Z^0_\mu - \frac{1}{4} g_Z (G_{X_1} v_1^2 + G_{X_2} v_2^2) Z^{0\mu} X_\mu$$
$$+ \frac{1}{8} (v_1^2 G_{X_1}^2 + v_2^2 G_{X_2}^2 v_2^2 + v_s^2 Q_{X_s}^2 g_X^2) X^\mu X_\mu$$

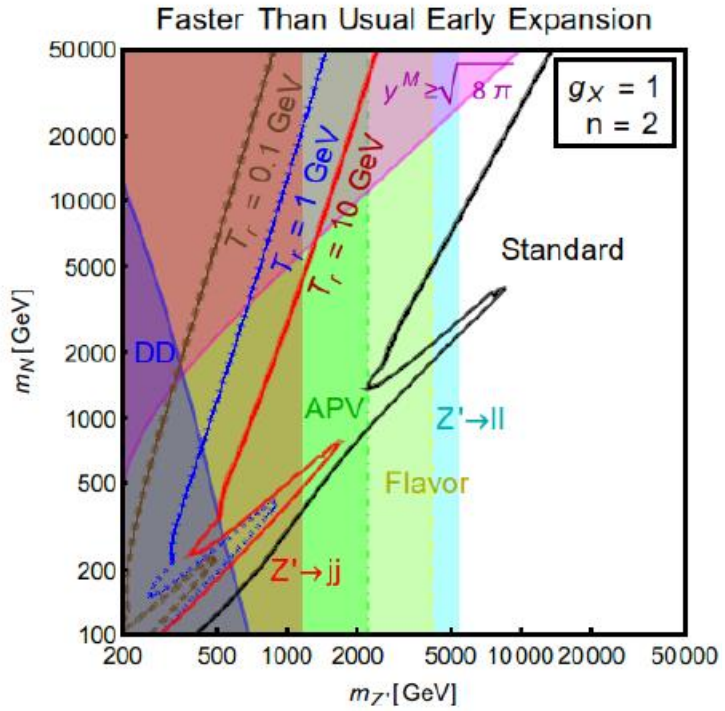
$$\mathcal{L}_{\rm NC} = - e J^\mu_{\rm em} A_\mu - \frac{g}{2\cos\theta_W} \cos\xi J^\mu_{NC} Z_\mu - \sin\xi \left(\epsilon e J^\mu_{em} + \epsilon_Z \frac{g}{2\cos\theta_W} J^\mu_{NC} \right) Z'_\mu +$$
$$+ \frac{1}{4} g_X \sin\xi \left[\left(Q^R_{Xf} + Q^L_{Xf}\right) \bar\psi_f \gamma^\mu \psi_f + \left(Q^R_{Xf} - Q^L_{Xf}\right) \bar\psi_f \gamma^\mu \gamma_5 \psi_f \right] Z_\mu +$$
$$- \frac{1}{4} g_X \cos\xi \left[\left(Q^R_{Xf} + Q^L_{Xf}\right) \bar\psi_f \gamma^\mu \psi_f - \left(Q^L_{Xf} - Q^R_{Xf}\right) \bar\psi_f \gamma^\mu \gamma_5 \psi_f \right] Z'_\mu +$$
$$- \frac{1}{4} Q_{N_1} g_X \cos\xi \cos\xi N_1 \gamma^\mu \gamma_5 N_1 Z'_\mu + \frac{1}{4} Q_{N_1} g_X \sin\xi N_1 \gamma^\mu \gamma_5 N_1 Z_\mu ,$$

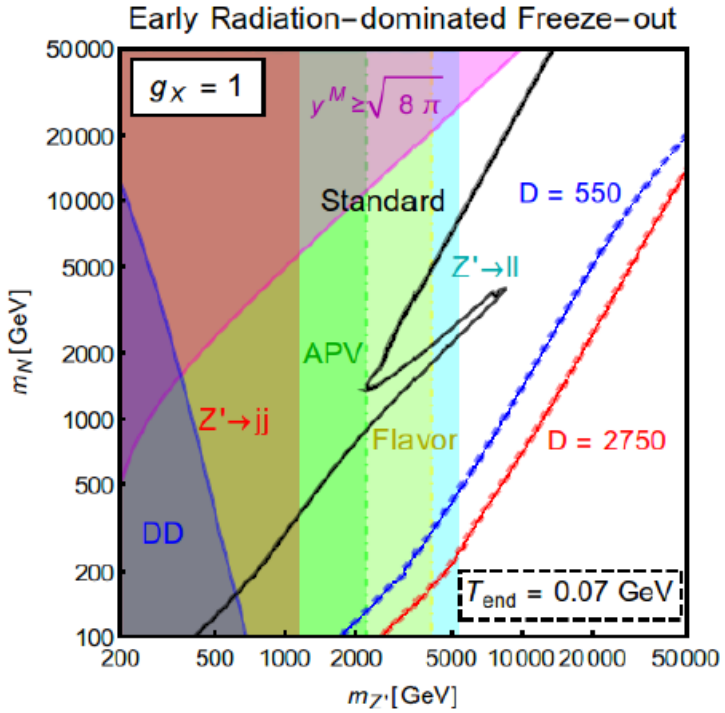


G.A., S. Profumo, F. S. Queiroz, C. Siquera JCAP 12 (2020) 030



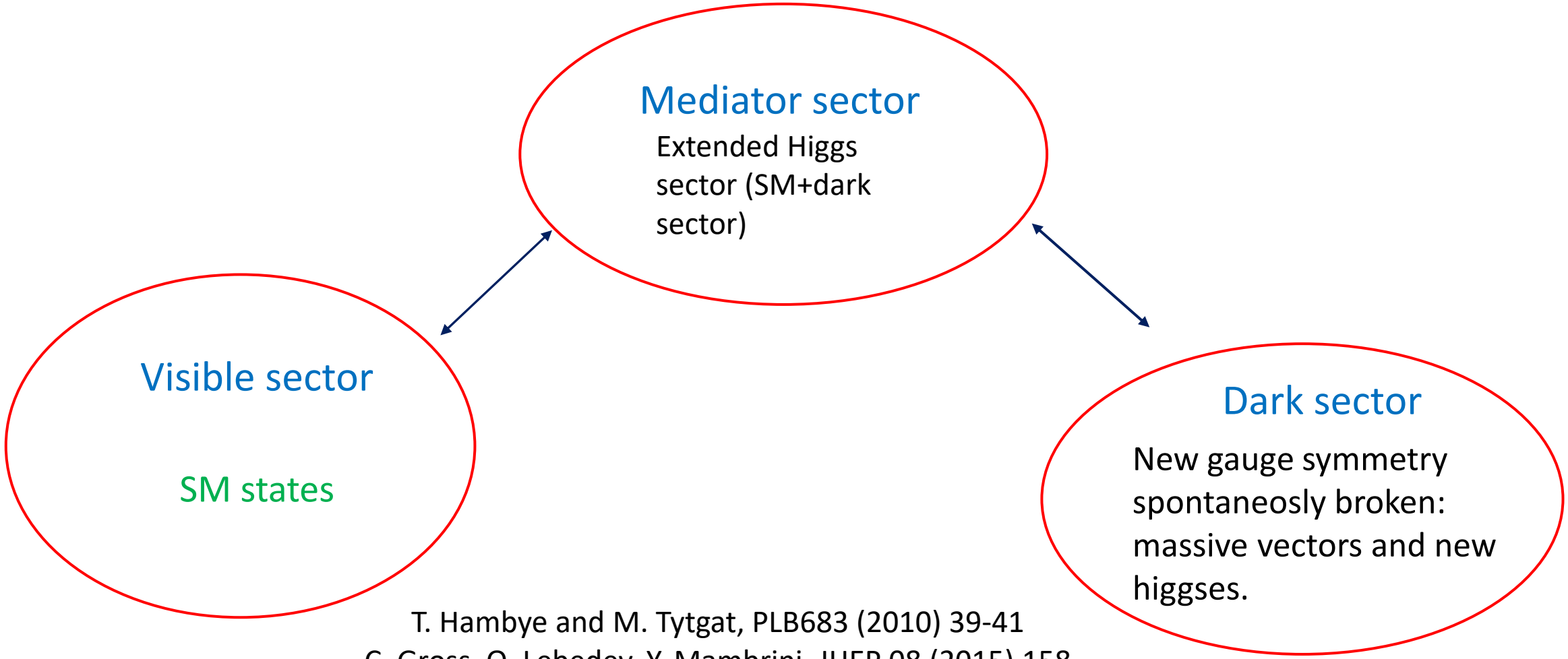
G.A., J. P. Neto, F. S. Queiroz, C. Siquera PRD105 (2022) 035016





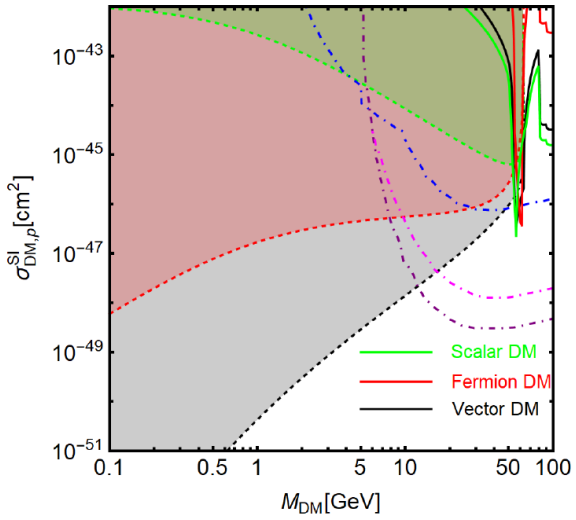
Third class of models:

Dark Matter from gauge symmetry



T. Hambye and M. Tytgat, PLB683 (2010) 39-41
C. Gross, O. Lebedev, Y. Mambrini, JHEP 08 (2015) 158
G.A. , C. Gross, O. Lebedev, Y. Mambrini, S. Pokorski, T. Toma, JHEP 12 (2016) 081

Invisible H decay vs Direct Detection

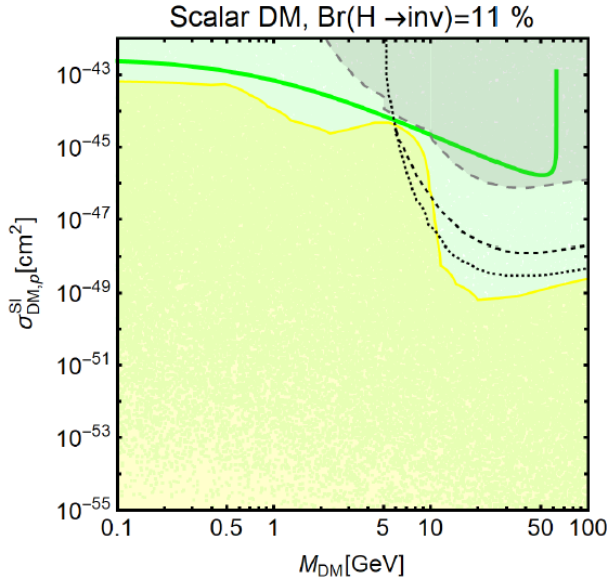


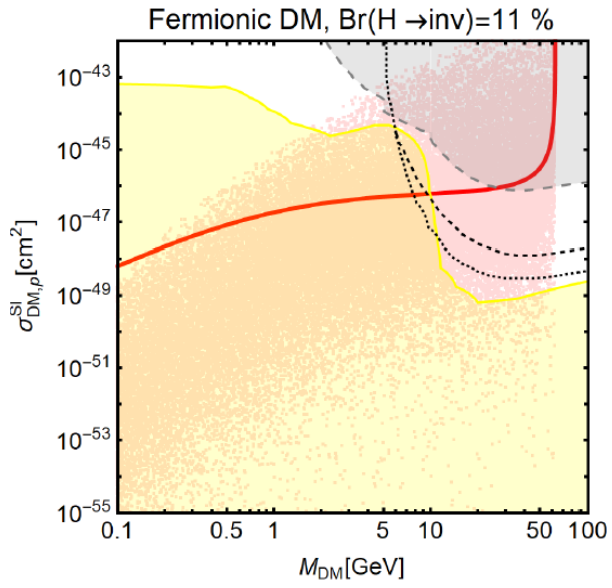
Effective Higgs portal

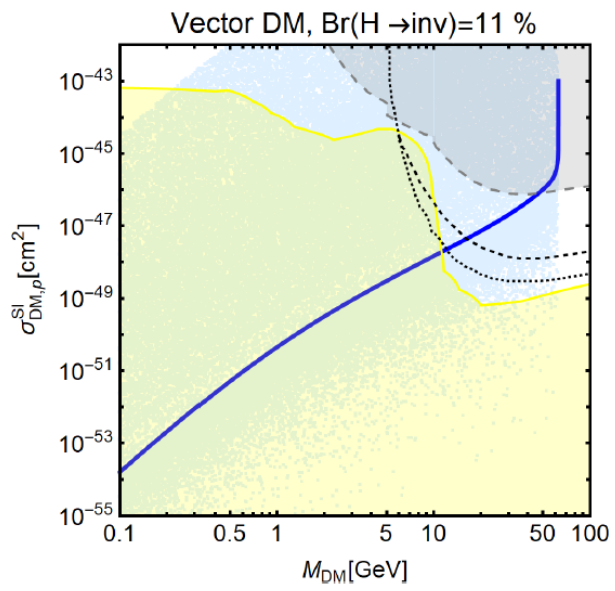
More realistic completion through mixing

$$\sigma_{DM,p} \propto \left(\frac{1}{M_{H_1}^2} - \frac{1}{M_{H_2}^2}\right)^2$$

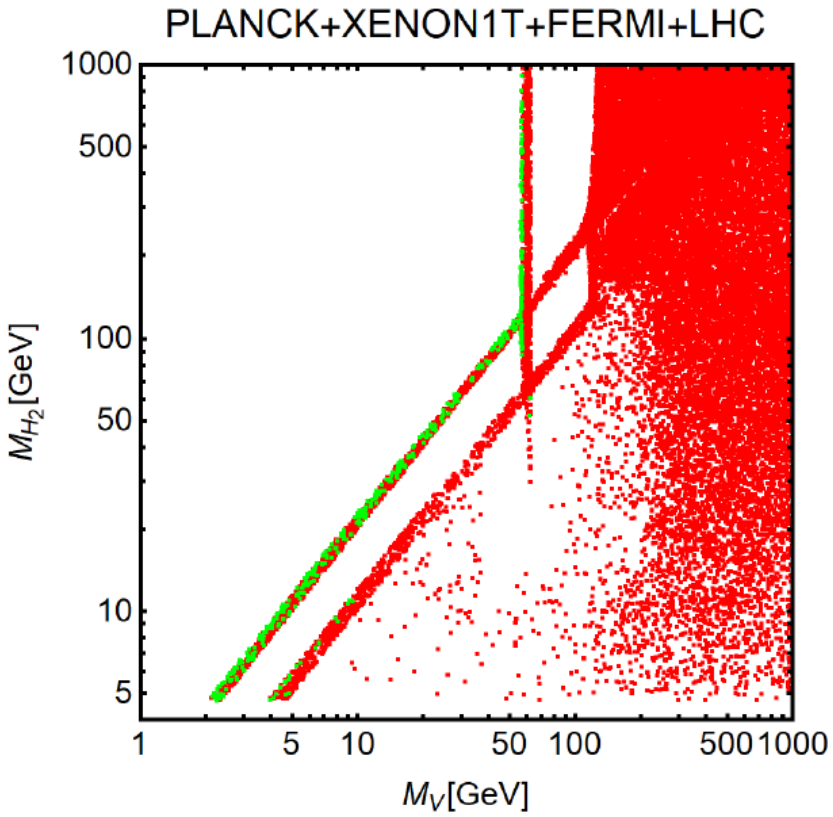
The additional degree of freedom crucially alters the LHC correlation plot.

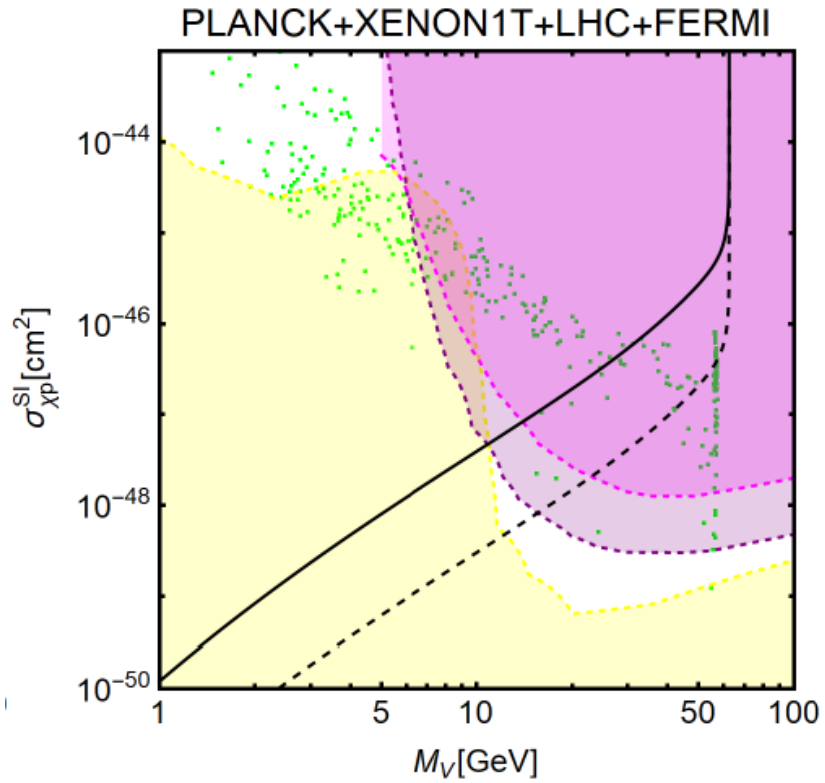






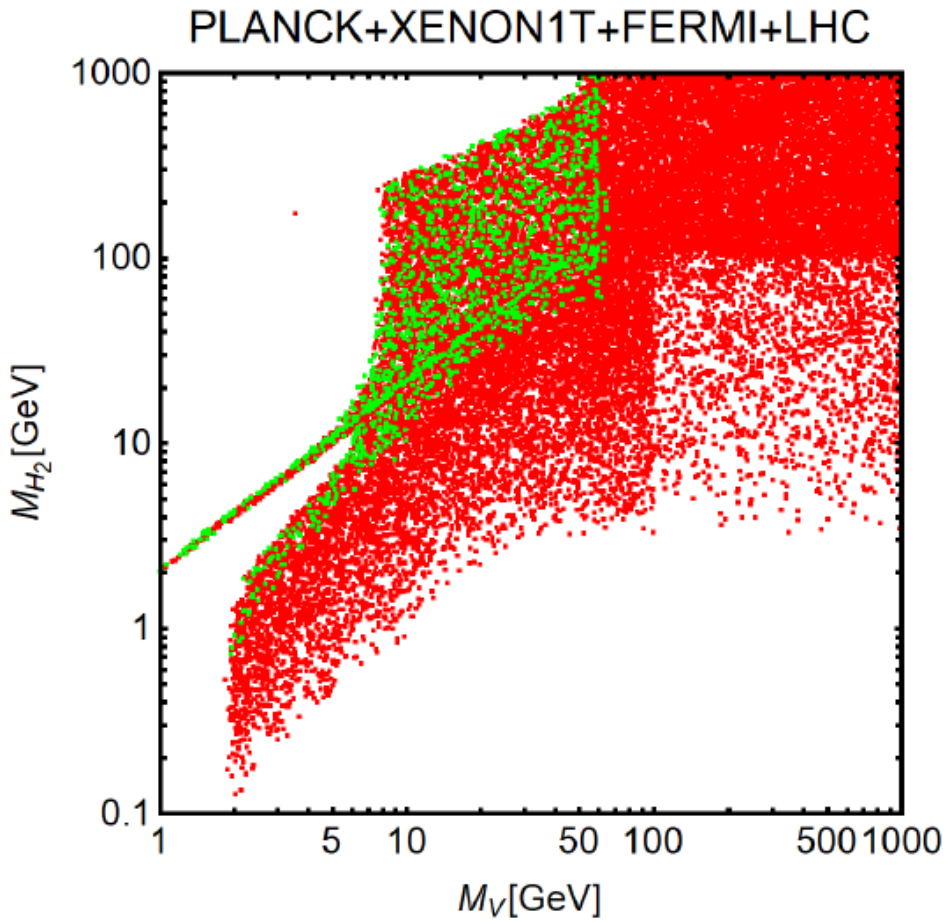
Vector Dark Matter (dark U(1))

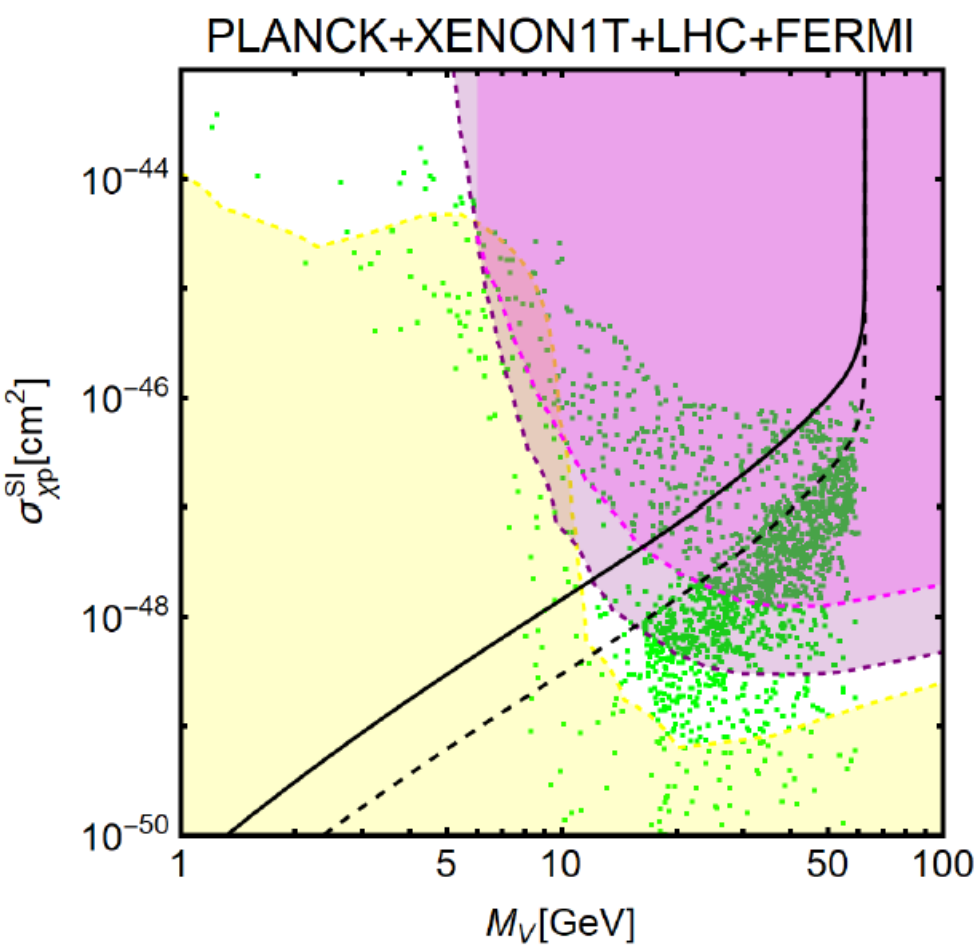




G.A., A. Djouadi,M. Kado, *Eur.Phys.J.C* 81 (2021) 7, 653
(see also S. Baek et al PRD 90 (2014) 055014, PRD 105 (2022) 015007)

V DM plus metastable V^3





$VV \to V^3V^3$ annihilation allow correct relic density for very heavy H_2. We can recover the EFT limit.

Conclusions

Models with extended Higgs sectors provide a nice correlation between DM and LHC searches.
On one side the feature interesting DM phenomenology, on the other offer peculiar collider signals.

We have provided a brief overview of some interesting examples.