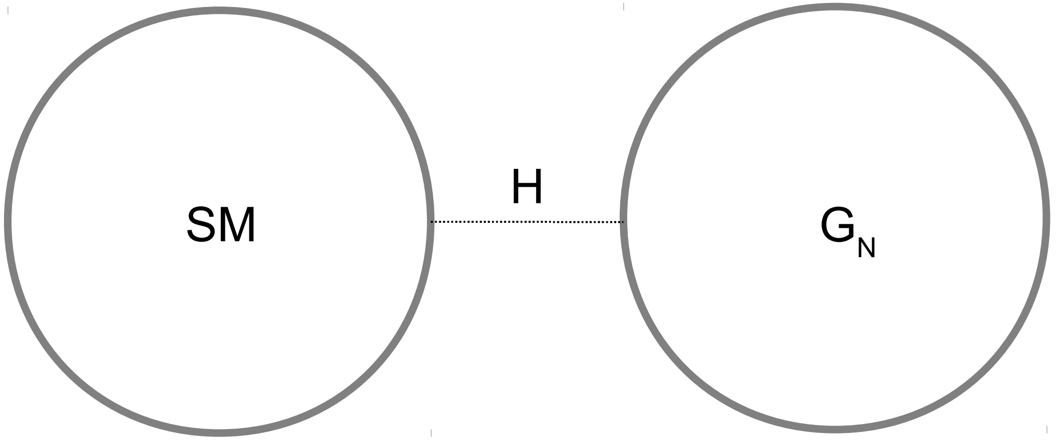
Gauge fields as Dark Matter

Oleg Lebedev

UNIVERSITY OF HELSINKI

University of Helsinki

The "Higgs portal" setup:



Higgs -- "hidden Higgs" mixing:

$$\Delta L = \lambda \, |H|^2 \, |S|^2$$

$\langle H \rangle = v$, $\langle S \rangle = v'$ $\Rightarrow$ 2 mass eigenstates

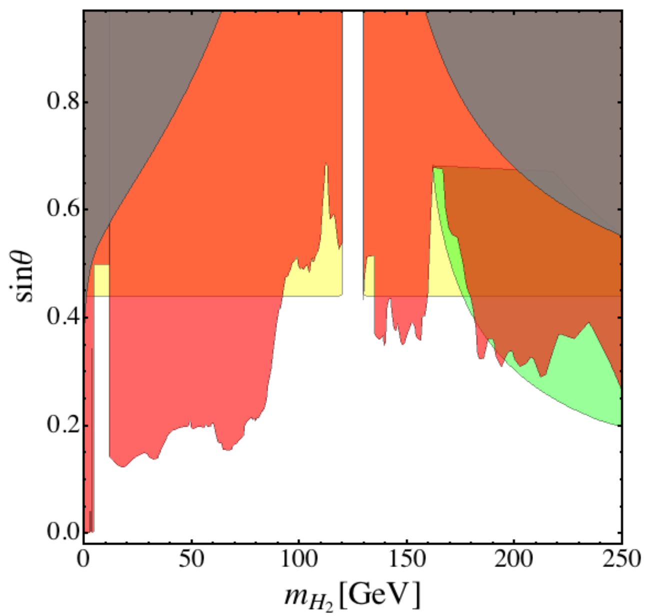
h couples to G_N !

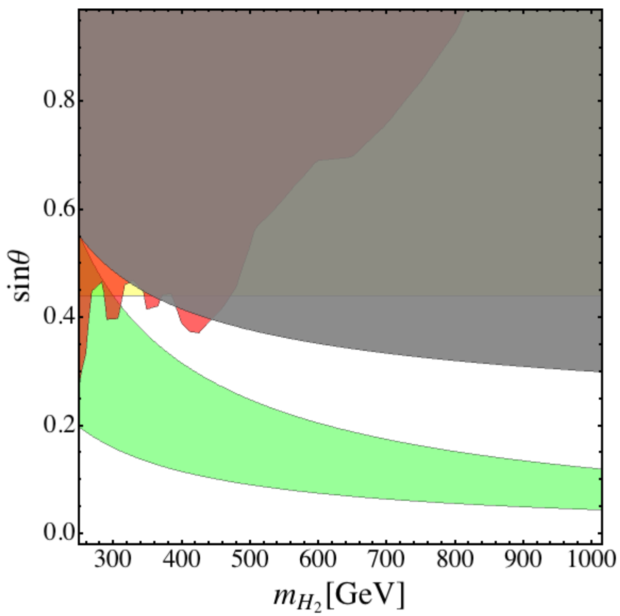
(''Higgsophilic'' *gauge bosons*)

Constraints on Higgs-singlet mixing :

H_1 = 125 GeV Higgs ; H_2 = extra Higgs ; θ = mixing angle

Falkowski, Gross, OL '15





Grey = EW precision data , Yellow = LHC Higgs couplings , Reddish = B-physics, LEP, LHC

Green (optional) = Higgs potential stability/perturbativity up to M_{Pl}

Gross,OL, Mambrini '15

DM candidates :

Lie groups possess discrete symmetries

↓

gauge fields as dark matter

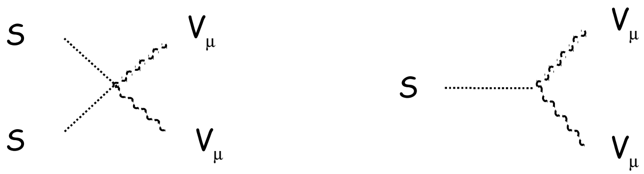
E.g. U(1) : $A_\mu \rightarrow -A_\mu$

Lee, OL, Mambrini '11

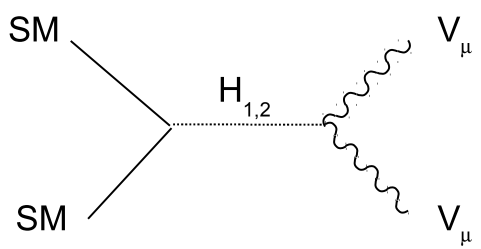
Higgs mechanism in the hidden sector :

$$\boxed{L = -1/4\, F_{\mu\nu} F^{\mu\nu} + D_\mu S^* D^\mu S - V(S) + \lambda/4\, \overline{H}H\, S^*S}$$

$$S \longrightarrow \mathrm{VEV}$$



SM couplings:



$\Rightarrow$ Z_2

gauge invariance (+ minimal field content)

$\Downarrow$

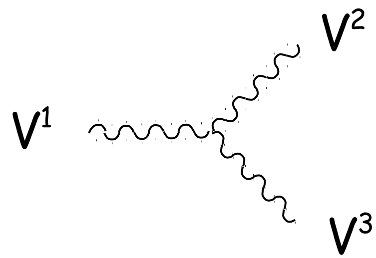
Z_2

$\Downarrow$

gauge fields are natural DM candidates

Hambye '08
Gross,OL, Mambrini '15

Non-abelian case:



$\Rightarrow$ Z_2 odd

But there are 2 Z_2's:

$V^{1,2} \rightarrow -V^{1,2} \quad , \quad V^3 \rightarrow V^3$

$V^{1,3} \rightarrow -V^{1,3} \quad , \quad V^2 \rightarrow V^2$

$\Rightarrow$ V^a = stable

$$\text{hidden Higgs} = \begin{pmatrix} 0 \\ v \end{pmatrix}$$

$$\sigma_1 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}; \quad \sigma_2 = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}; \quad \sigma_3 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}.$$

Z_2 : reflects real generators

complex (or "charge") conjugation = outer automorphism

Z_2' : reflects off-diagonal generators with non-zero elements in the first row

gauge transformation

Gross,OL, Mambrini '15

General SU(N) case

$$\left[T^a, T^b\right] = i f^{abc} T^c$$

Z_2 : reflects real generators

Z_2' : reflects non-Cartan generators with non-zero first row (Pauli-like basis)

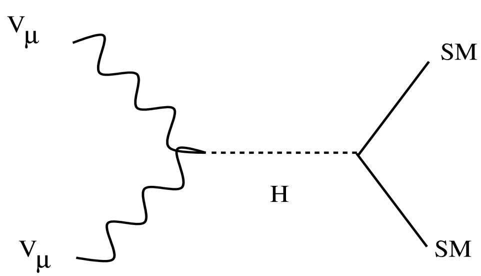
Higgsing:

$$\underbrace{\begin{pmatrix} 0 \\ 0 \\ .. \\ 0 \\ a \end{pmatrix} \begin{pmatrix} 0 \\ 0 \\ .. \\ b_1 \\ b_2 \end{pmatrix} \; \ldots \; \begin{pmatrix} 0 \\ z_1 \\ .. \\ .. \\ z_{N-1} \end{pmatrix}}_{N-1} \Rightarrow$$

$Z_2 \times Z_2'$ preserved if CP is conserved

DM phenomenology :

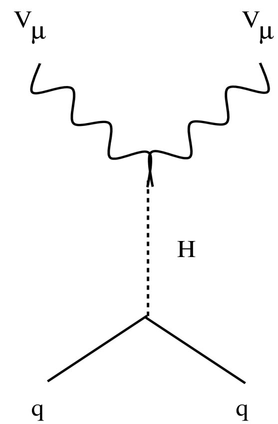
annihilation



$< \sigma v >$

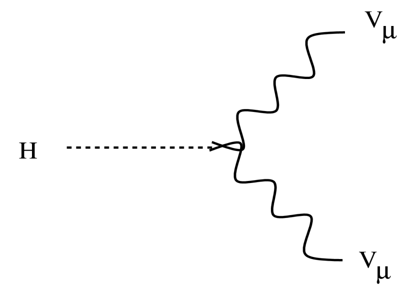
(+ other channels)

DM-nucleon scattering



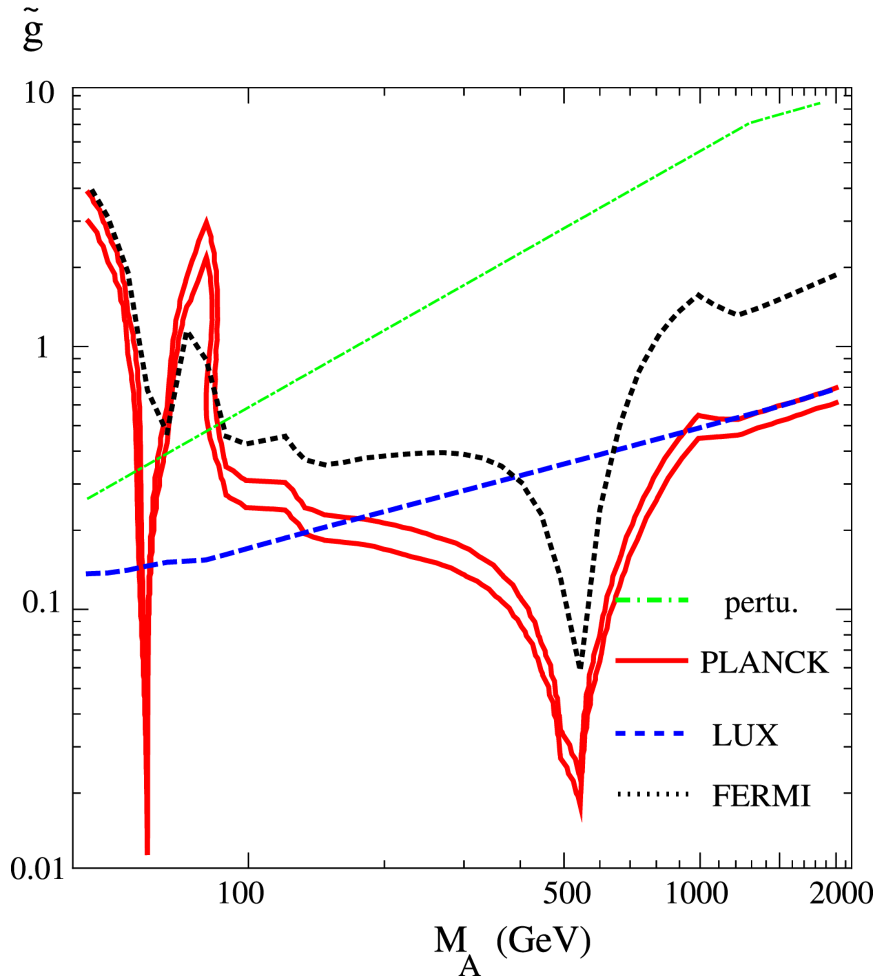
σ^{SI}_{S-P}

invisible Higgs decay



Γ^{inv}_{H}

Gross,OL, Mambrini '15



U(1)

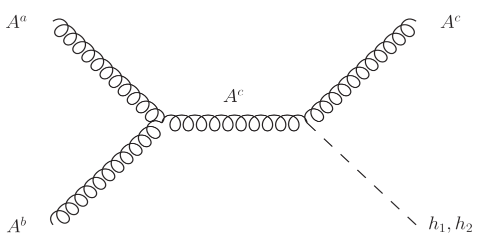
$\sin\theta = 0.3$

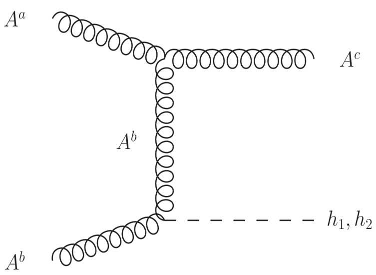
$M_{H2} = 1$ TeV

(may also impose Higgs potential stability Duch, Grzadkowski, McGarrie '15)

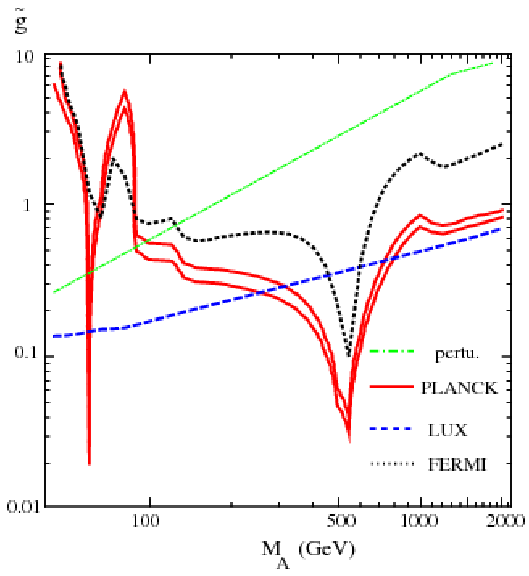
Non-abelian case :

New features = *semi-annihilation, suppressed annihilation* (~ 1/N)





Hambye '08



Gross,OL, Mambrini '15

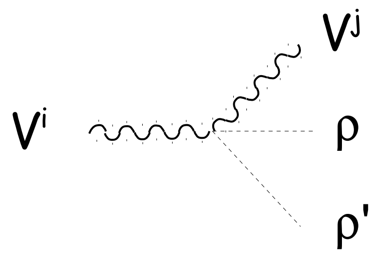
SU(2)

$\sin\theta = 0.3$

M_{H2}= 1 TeV

Gross,OL, Mambrini '15

Higher SU(N) :



⇒ heavy fields decay

Lightest stable gauge fields: **$V^{1,2}$, V^3** (in SU(2) notation)

$$\mathbf{M_{V1} = M_{V2} > M_{V3}}$$

⇓

two non-degenarate components

(consequence of the intrinsic $Z_2 \times Z_2$)

E.g. SU(3) :

reduces to SU(2) for $v_1 >> v_2$

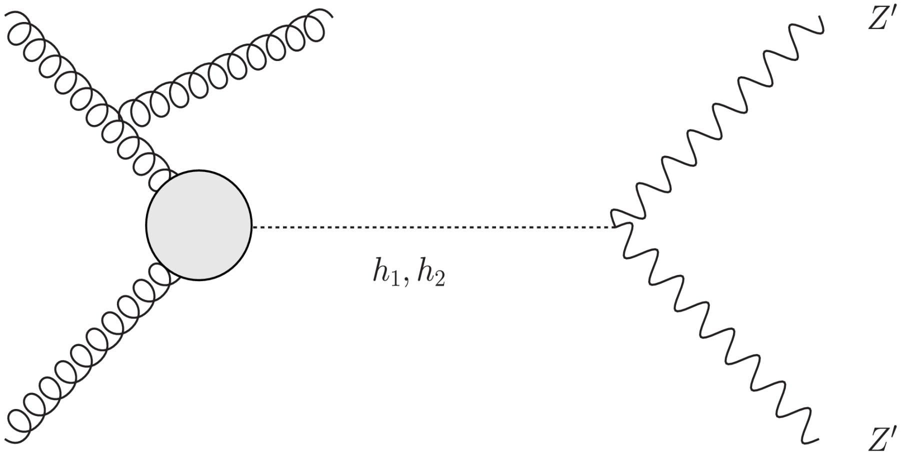
(otherwise complicated)

Also possible : **mixed scalar-vector DM**

(Takashi Toma's talk)

Higgsophilic gauge bosons at the LHC:

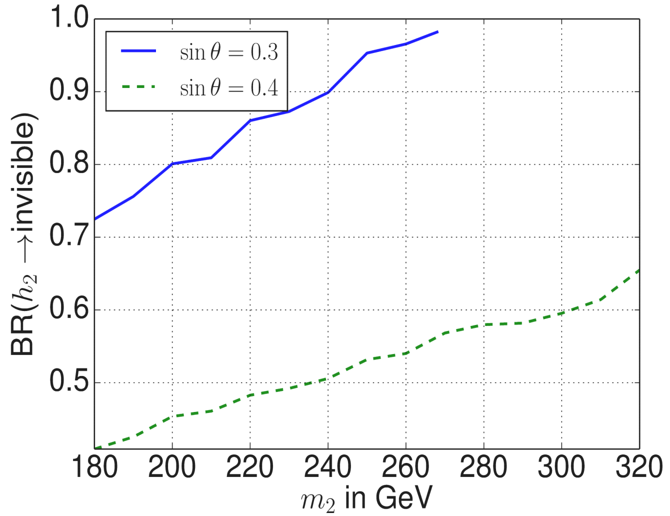
monojets (or VBF) + missing E_T

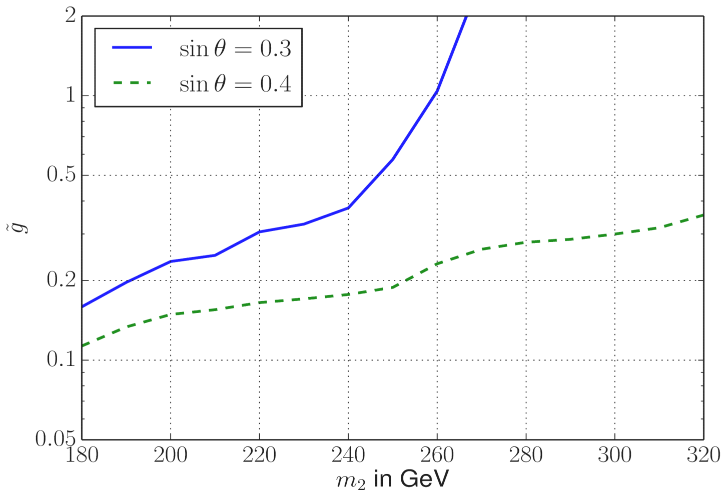


efficient for $m_2 > 2\, m_{Z'}$

Kim, OL ,Schmeier '15

Monojet results with 600 fb^{-1} :





+ similar results for VBF with already 300 fb^{-1}

Conclusion

- gauge theories contain discrete symmetries
- gauge fields are natural DM candidates
- exhibit healthy phenomenology