Gauge fields as dark matter

Christian Gross
(Helsinki University)

30.9.15, DESY theory workshop, Hamburg

(Based on JHEP 1508 (2015) 158 with O. Lebedev and Y. Mambrini)

The setup:

Standard Model:

SU(3) x SU(2) x U(1) gauge symmetry

Higgs doublet H breaks electroweak symmetry

`Higgs portal'

$|H|^2 \, |\phi_i|^2$

Dark sector:

Dark $SU(N)_d$ [or $U(1)_d$] gauge symmetry

Minimal set of Dark Higgses ϕ_i necessary to break dark gauge symmetry

The massive dark gauge fields are stable and can serve as WIMP-type Dark Matter

$U(1)_d$ vector dark matter

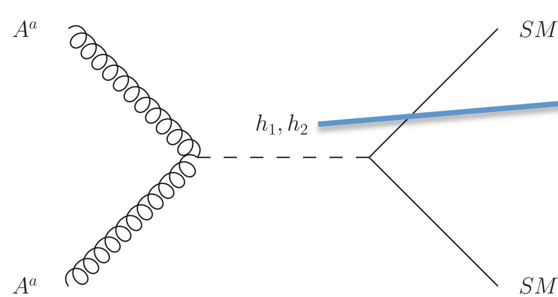
$$\mathcal{L}_{\rm dark} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + |D_\mu\phi|^2 - V(\phi)$$

ϕ: complex scalar
$\phi = \frac{1}{\sqrt{2}}(\tilde{v} + \rho)$ in unitary gauge

A_μ is stable due to Z_2-symmetry: $\begin{cases} \phi \to \phi^* \\ A_\mu \to -A_\mu \end{cases}$

[Lebedev,Lee,Mambrini, 2011]

DM annihilation:



h_1, h_2 are the mass eigenstates of the dark Higgs ρ and $SU(2)_L$-Higgs h

$SU(2)_d$ vector dark matter [cf. Hambye, 2008]

$$\mathcal{L}_{\rm dark} = -\frac{1}{4}\sum_{a=1}^{3} F^a_{\mu\nu}F^{a\mu\nu} + |D_\mu\phi|^2 - V(\phi)$$

ϕ: **2** of $SU(2)_d$

$\phi = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 \\ \tilde{v}+\rho \end{pmatrix}$ in unitary gauge

$A^a_\mu \rightarrow -A^a_\mu$ is not a symmetry, due to triple gauge boson vertex!

Instead, there arises a $Z_2 \times Z'_2$ symmetry:

$$Z'_2: \begin{cases} \phi \rightarrow \phi^* \\ A^1_\mu \rightarrow -A^1_\mu \\ A^3_\mu \rightarrow -A^3_\mu \end{cases}$$

- Z'_2 reflects gauge fields corresponding to real generators T^a
- Reason for invariance of $(F_{\mu\nu})^2$: $T^a \rightarrow -(T^a)^*$ is an automorphism of SU(N)

$$Z_2: \begin{cases} A^1_\mu \rightarrow -A^1_\mu \\ A^2_\mu \rightarrow -A^2_\mu \end{cases}$$

- Z_2 reflects gauge fields corresponding to generators T^a with nonzero off-diagonal entries in the first row
- Reason for invariance: This is a $SU(N)_d$ symmetry transformation

Generalisation to $SU(N)_d$

Can `sequentially‘ break $SU(N)_d$ completely with N-1 Higgses ϕ_i in the fundamental representation of $SU(N)_d$

Assuming the potential is CP-invariant and CP is unbroken in the vacuum, the $Z_2 \times Z'_2$ symmetry generalises to $SU(N)_d$ with N≥3!

→ As for $SU(2)_d$, one therefore has 3 stable gauge fields also for $SU(N)_d$ with N≥3.

Difference to $SU(2)_d$:
For N≥3 have mass splitting among DM. Two DM vectors are always degenerate in mass while the third one is ligther.

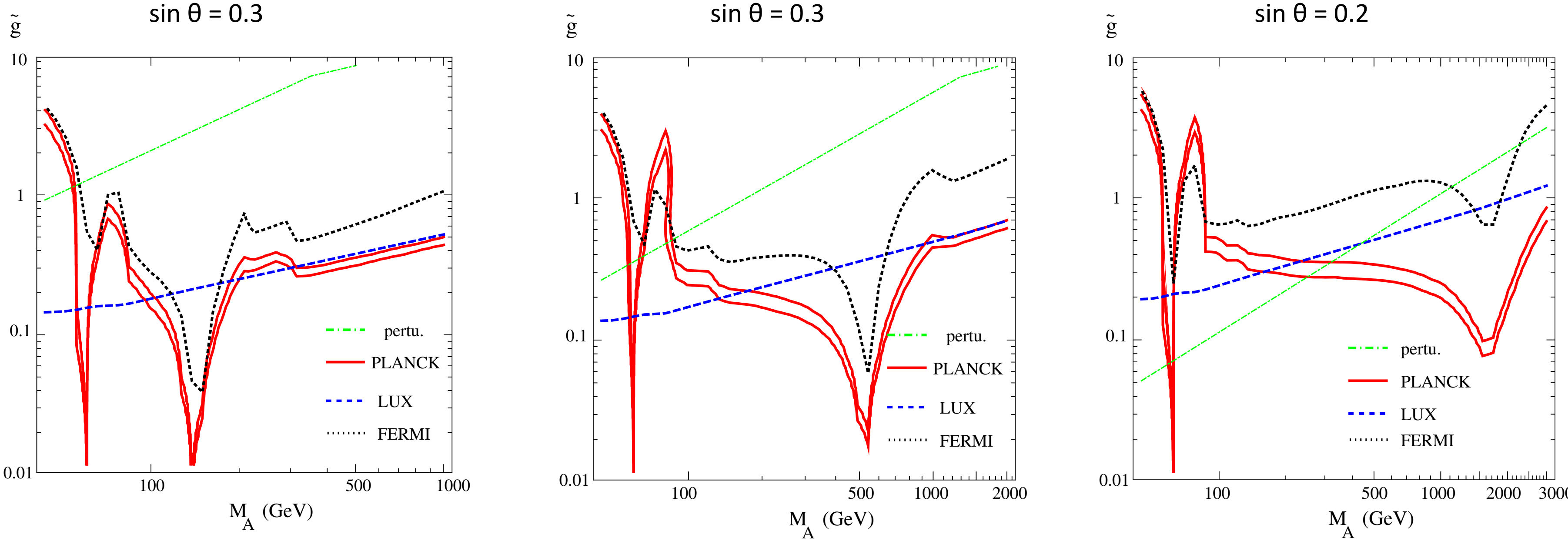
Phenomenology of $U(1)_d$ vector DM

(sin θ : h-ρ mixing angle)

m_{h2} = 280 GeV
sin θ = 0.3

m_{h2} = 1 TeV
sin θ = 0.3

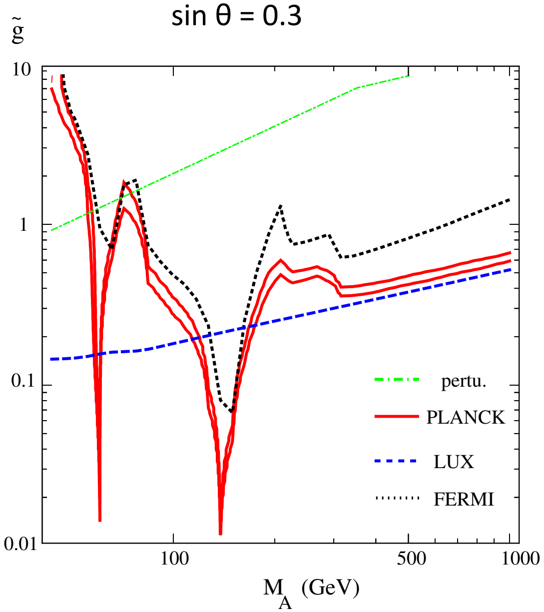
m_{h2} = 3 TeV
sin θ = 0.2



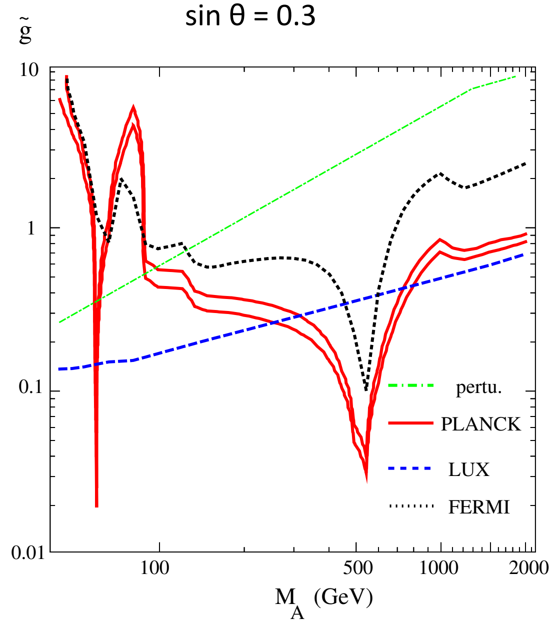
Phenomenology of $SU(2)_d$ vector DM

(sin θ : h-ρ mixing angle)

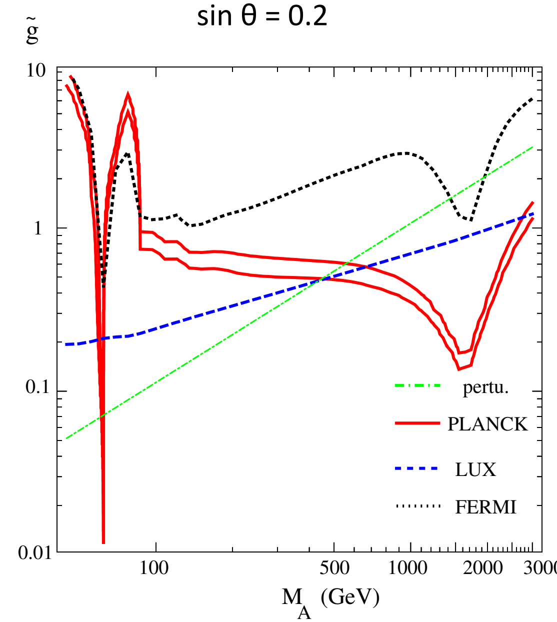
m_{h2} = 280 GeV
sin θ = 0.3



m_{h2} = 1 TeV
sin θ = 0.3



m_{h2} = 3 TeV
sin θ = 0.2



Main difference for phenomenology:
Only DM vectors with the same group index can annihilate!

→ Annihilation cross-section is decreased

→ This needs to be compensated by increased gauge coupling

By contrast: direct detection limits are unchanged

Summary

- massive gauge fields of a $U(1)_d$ or $SU(N)_d$, spontaneously broken with a minimal CP-conserving dark Higgs sector, can be viable DM candidates
- Stability of $SU(N)_d$ DM due to $Z_2 \times Z'_2$ symmetry (which is <u>not</u> put in by hand)
- For N=2, DM consists of 3 vectors degenerate in mass, for N≥3 two DM vectors are degenerate in mass and the third one is lighter
- Large regions of viable parameter space