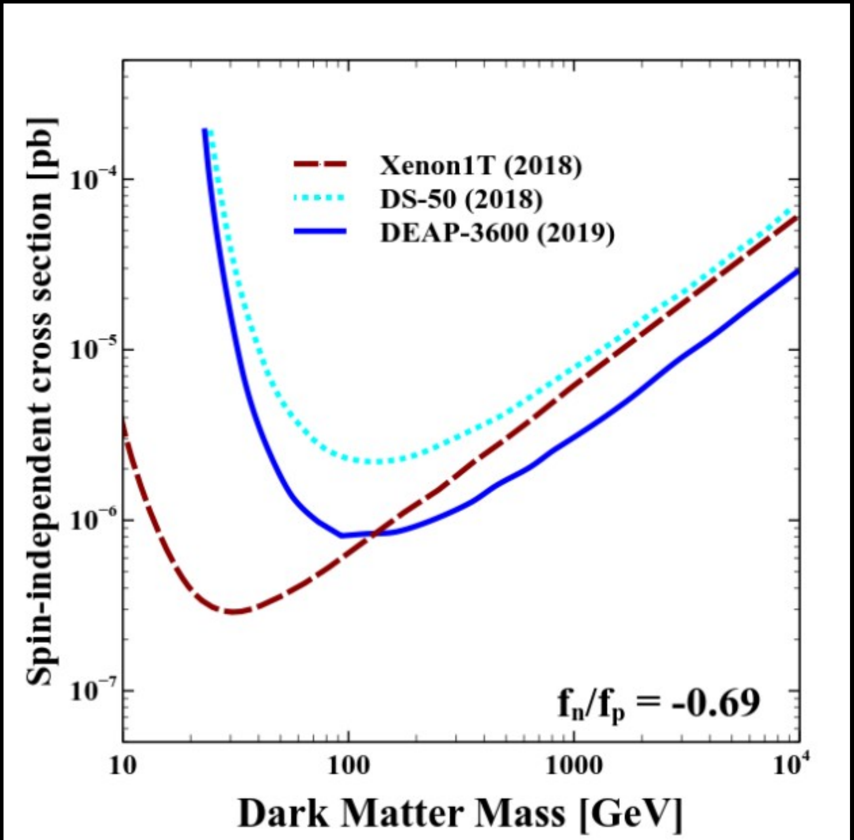
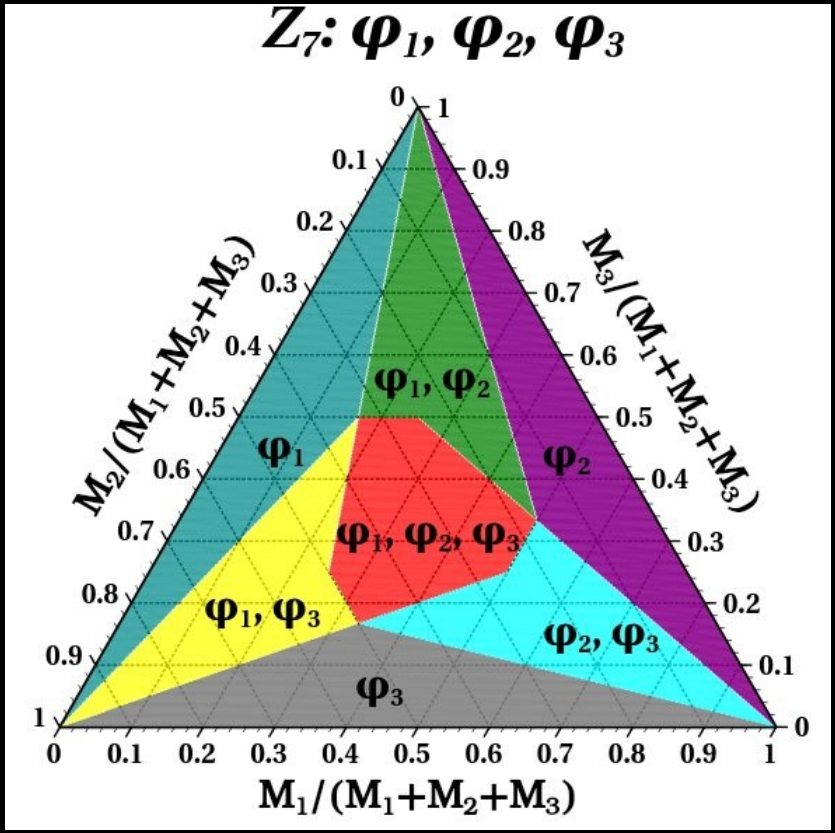
Dark Matter: challenges and open problems





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We don't know much about the dark matter particle

What we know:

It's stable, neutral and "cold"

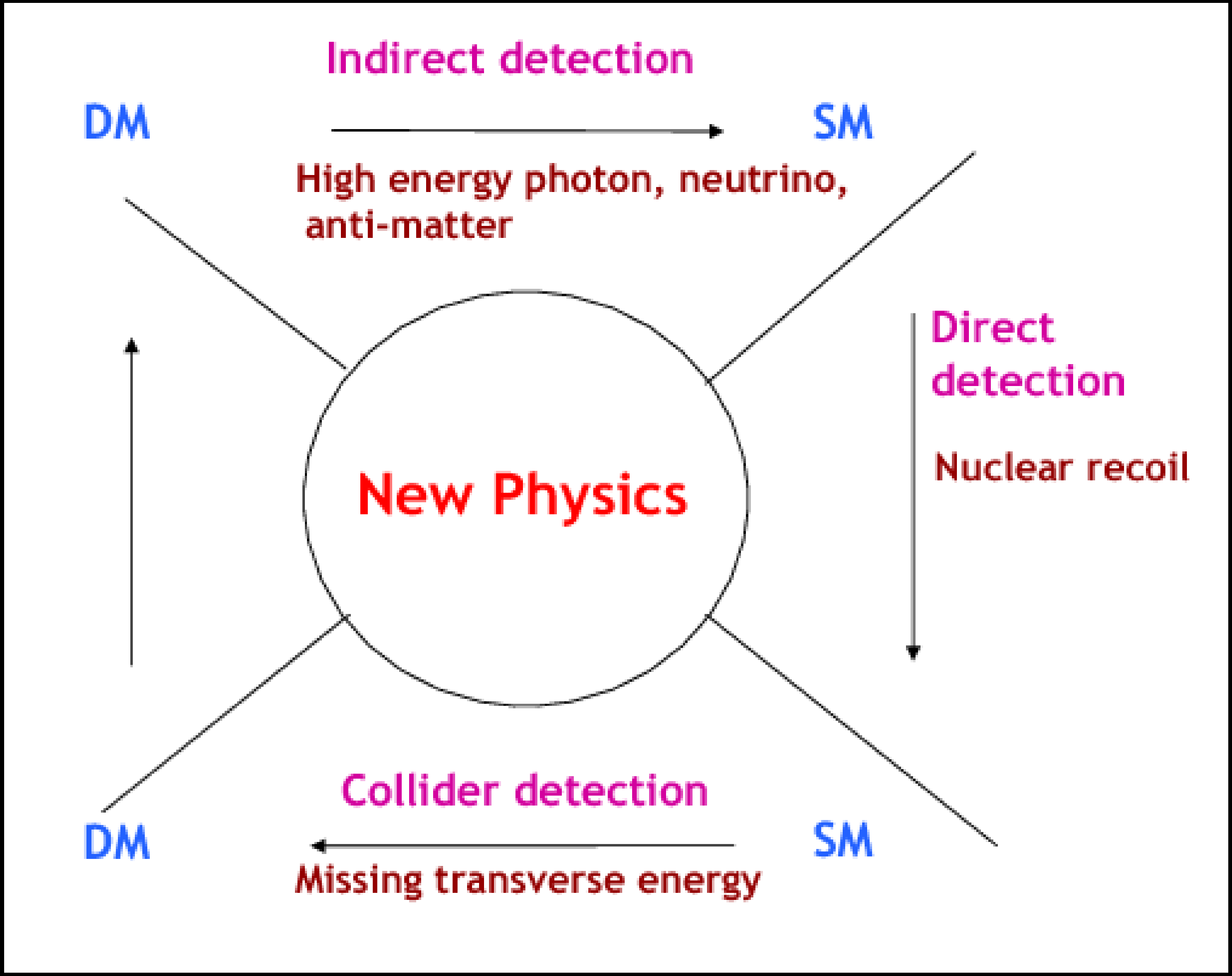
It does not interact much

It's a relic from the early Universe

What we don't know:

Its mass, its spin.
Is it real or complex?
Why is it stable?
Its quantum numbers.
How can it be detected?
Are there several of them?
Is it connected to other problems?
How was it produced?
How is it distributed? ...

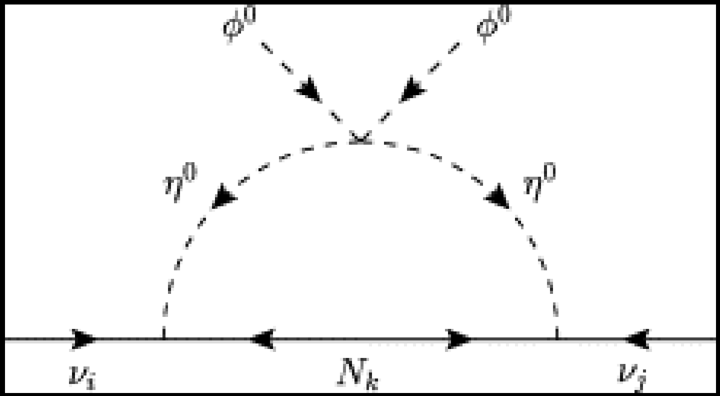
During the next few years we may be able to answer some of these questions



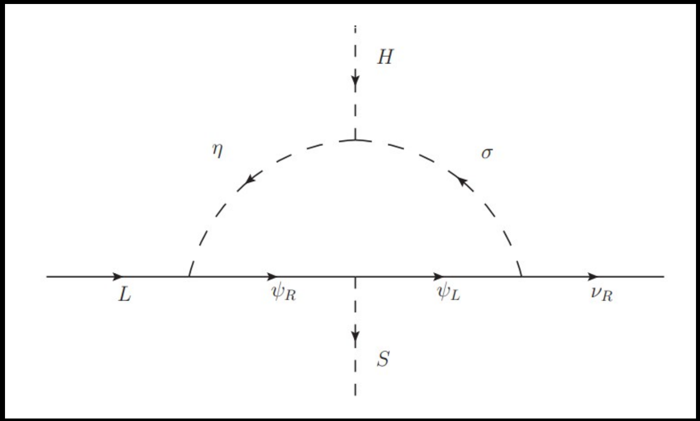
Is dark matter related to neutrinos?

They both require new physics

At the TeV scale?



ν-masses at 1-loop from DM



Also for Dirac ν-masses

Dark matter may be related to neutrinos via anomaly cancellation

Similar to quarks and leptons in the SM

A new model based on a B-L symmetry

The DM consists of two Dirac particles

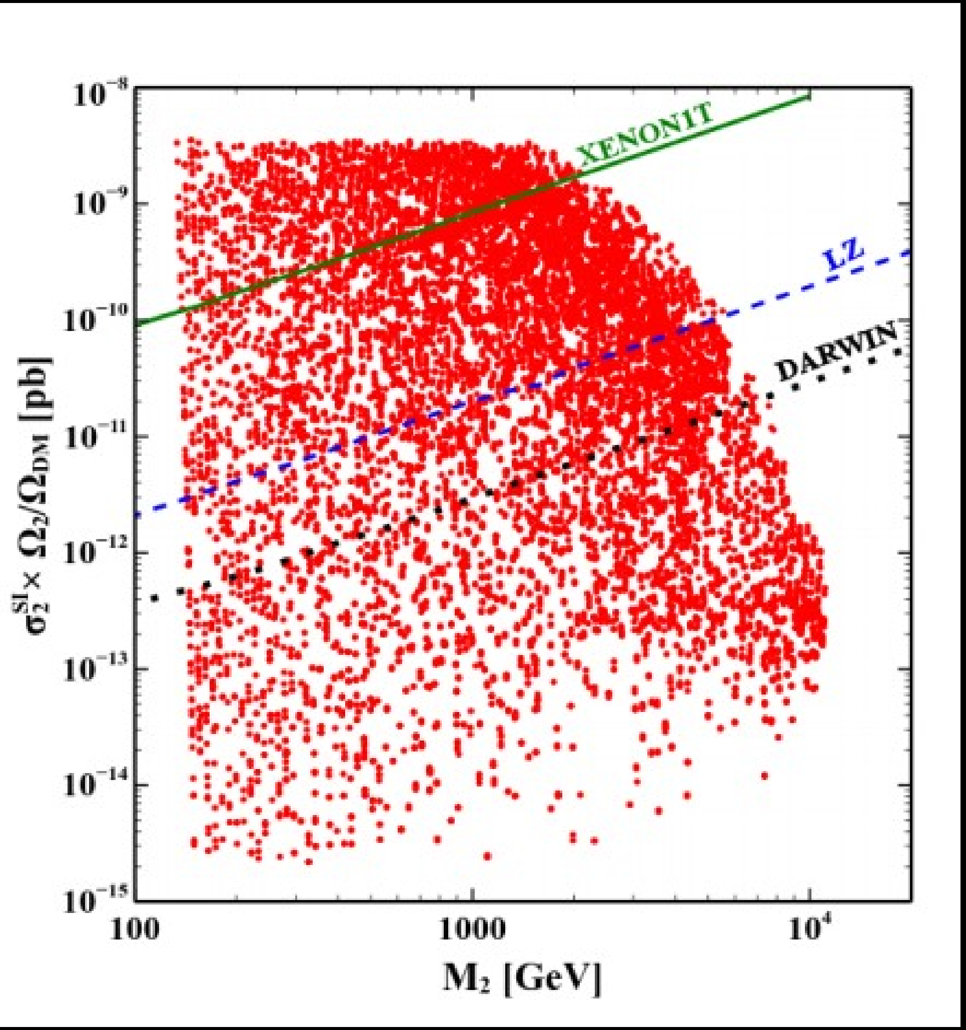
Particles	$U(1)_{B-L}$	$(SU(3)_c,\, SU(2)_L,\, U(1)_Y)$
Q_{Li}	$1/3$	$(\mathbf{3},\, \mathbf{2},\, 1/6)$
u_{Ri}	$1/3$	$(\overline{\mathbf{3}},\, \mathbf{1},\, 2/3)$
d_{Ri}	$1/3$	$(\overline{\mathbf{3}},\, \mathbf{1},\, -1/3)$
L_i	-1	$(\mathbf{1},\, \mathbf{2},\, -1/2)$
e_{Ri}	-1	$(\mathbf{1},\, \mathbf{1},\, -1)$
N_{R1}	-1	$(\mathbf{1},\, \mathbf{1},\, 0)$
N_{R2}	-1	$(\mathbf{1},\, \mathbf{1},\, 0)$
ξ_L	$10/7$	$(\mathbf{1},\, \mathbf{1},\, 0)$
η_R	$-4/7$	$(\mathbf{1},\, \mathbf{1},\, 0)$
ζ_R	$-2/7$	$(\mathbf{1},\, \mathbf{1},\, 0)$
χ_L	$-9/7$	$(\mathbf{1},\, \mathbf{1},\, 0)$
H	0	$(\mathbf{1},\, \mathbf{2},\, 1/2)$
ϕ_1	1	$(\mathbf{1},\, \mathbf{1},\, 0)$
ϕ_2	2	$(\mathbf{1},\, \mathbf{1},\, 0)$

This model can be tested at the LHC and in direct detection experiments

Z' (B-L) searches at the LHC

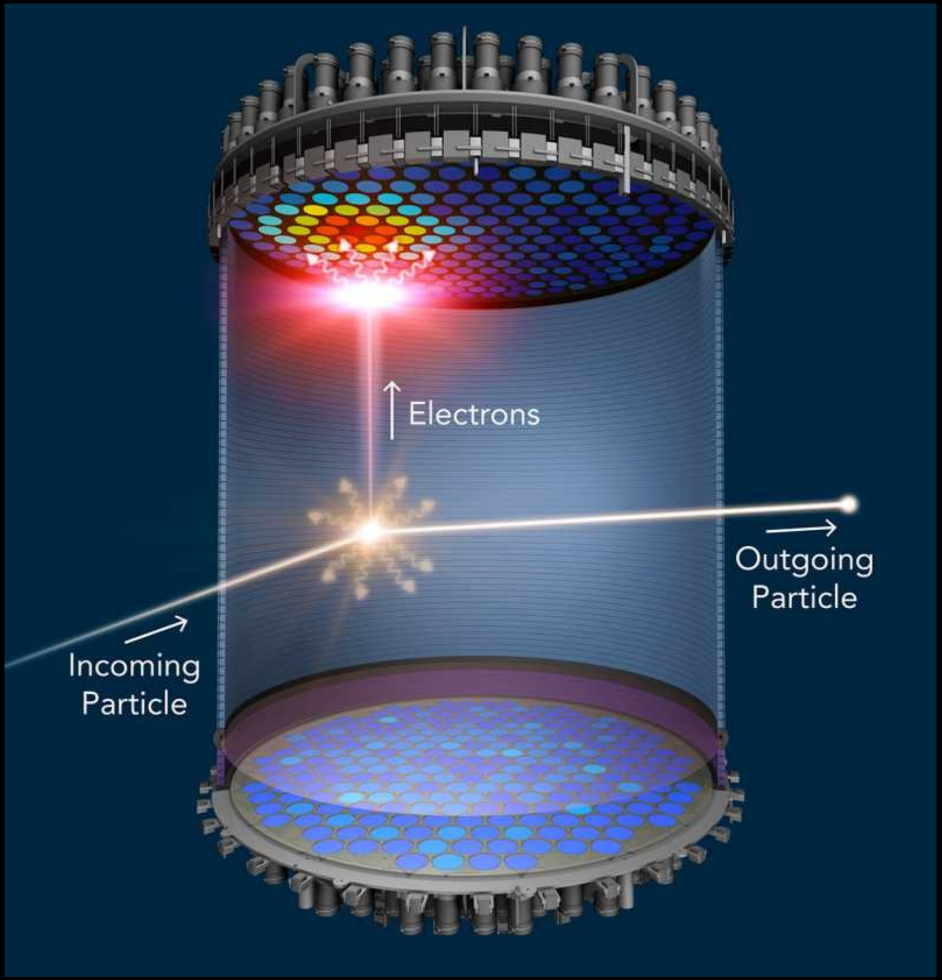
Current and future DD experiments

It also predicts a massless ν



Does the dark matter particle couple equally to protons and neutrons?

$$\sigma_0^{\mathrm{SI}} = \sigma_p \cdot \frac{\mu_A^2}{\mu_p^2} \cdot [Z \cdot f^p + (A - Z) \cdot f^n]^2$$



$f_p = f_n$ is the usual assumption

But it does not have to be so

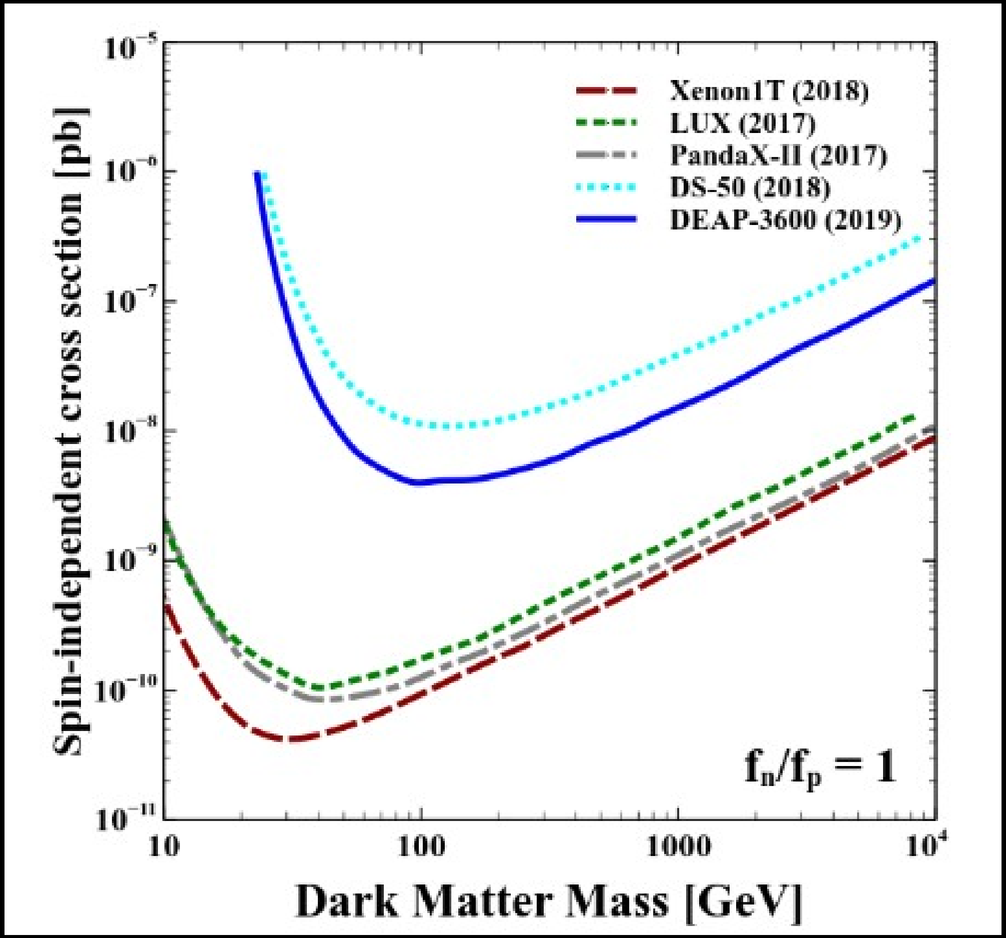
Several simple dark matter models give rise to isospin-violating DM

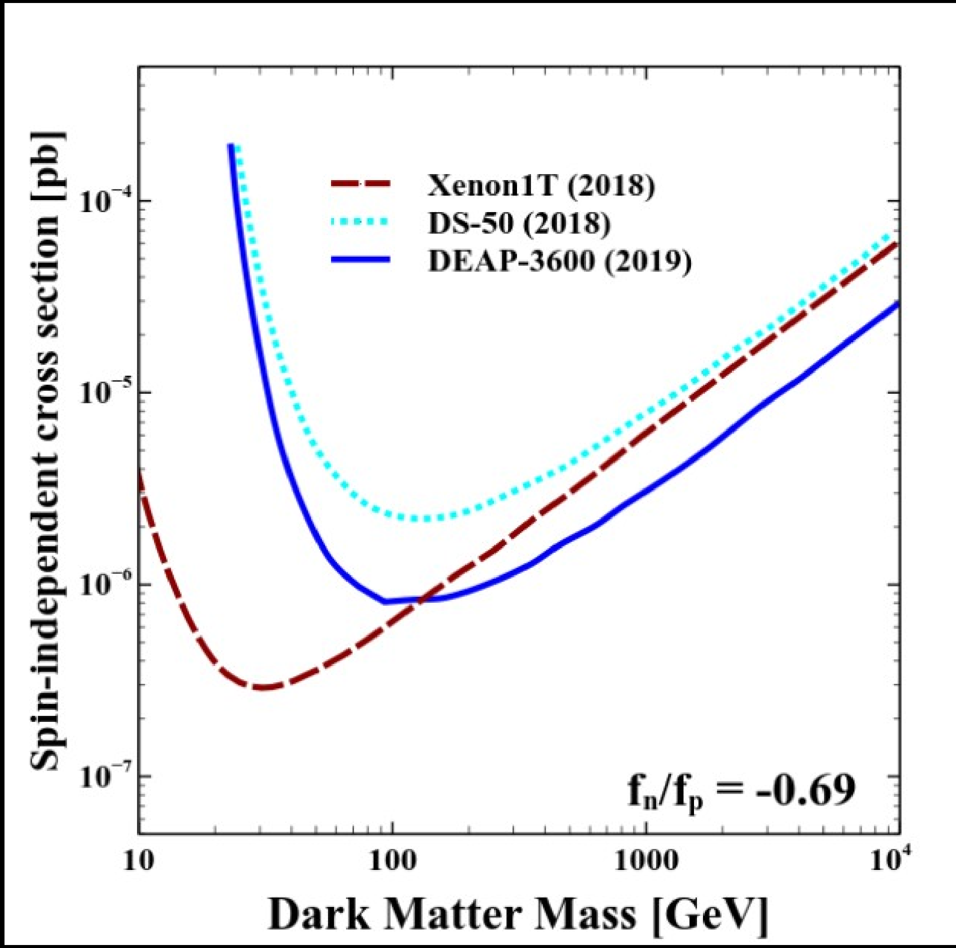
Dark-Photon Mediation: $f_n/f_p = 0$

Z Mediation: $f_n/f_p = -12.5$

Light Squark-Mediation: $f_n/f_p = 0.7\ (\tilde{u})$ or $1.5\ (\tilde{d})$

The interpretation of the experimental limits depend on this assumption





Future signals may allow to test if the coupling is really the same

Do dark matter interactions violate P or CP?

3 possibilities for spin-0 DM

Scalar, pseudoscalar, or CPV

DM decaying into gamma-ray lines

$$\mathscr{L} = \frac{a}{M_{pl}}\varphi B_{\mu\nu}B^{\mu\nu} + \frac{b}{M_{pl}}\varphi B_{\mu\nu}\tilde{B}^{\mu\nu} + \frac{c}{M_{pl}}\varphi W^{I}_{\mu\nu}W^{I\mu\nu} + \frac{d}{M_{pl}}\varphi W^{I}_{\mu\nu}\widetilde{W}^{I\mu\nu}$$

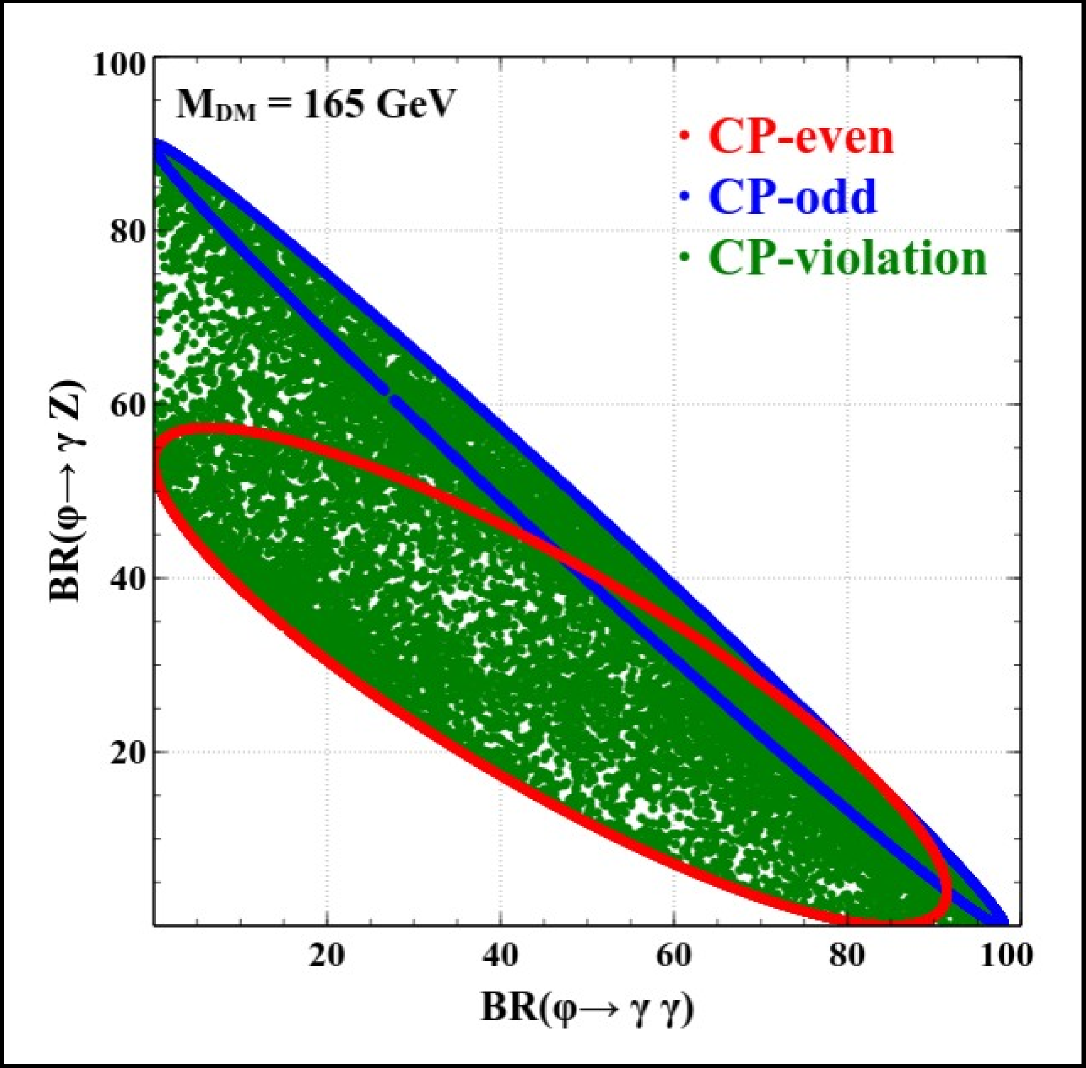
Via dim-5 operators

The correlations between different decays depend on the CP properties of the DM

The CP nature may be determined

For annihilating DM is not so simple

Perhaps at the LHC, or DD?



How many dark matter particles are there?

Just one is the simplest option

But several are allowed

Guaranteeing the stability is tricky

Even for one DM particle

We lack a theoretical framework

Z_N (N≥4) symmetries can simultaneously stabilize several (scalar) DM particles

They often appear as remnants of U(1)

The stability depends on the masses