Theory Landscape and new Directions

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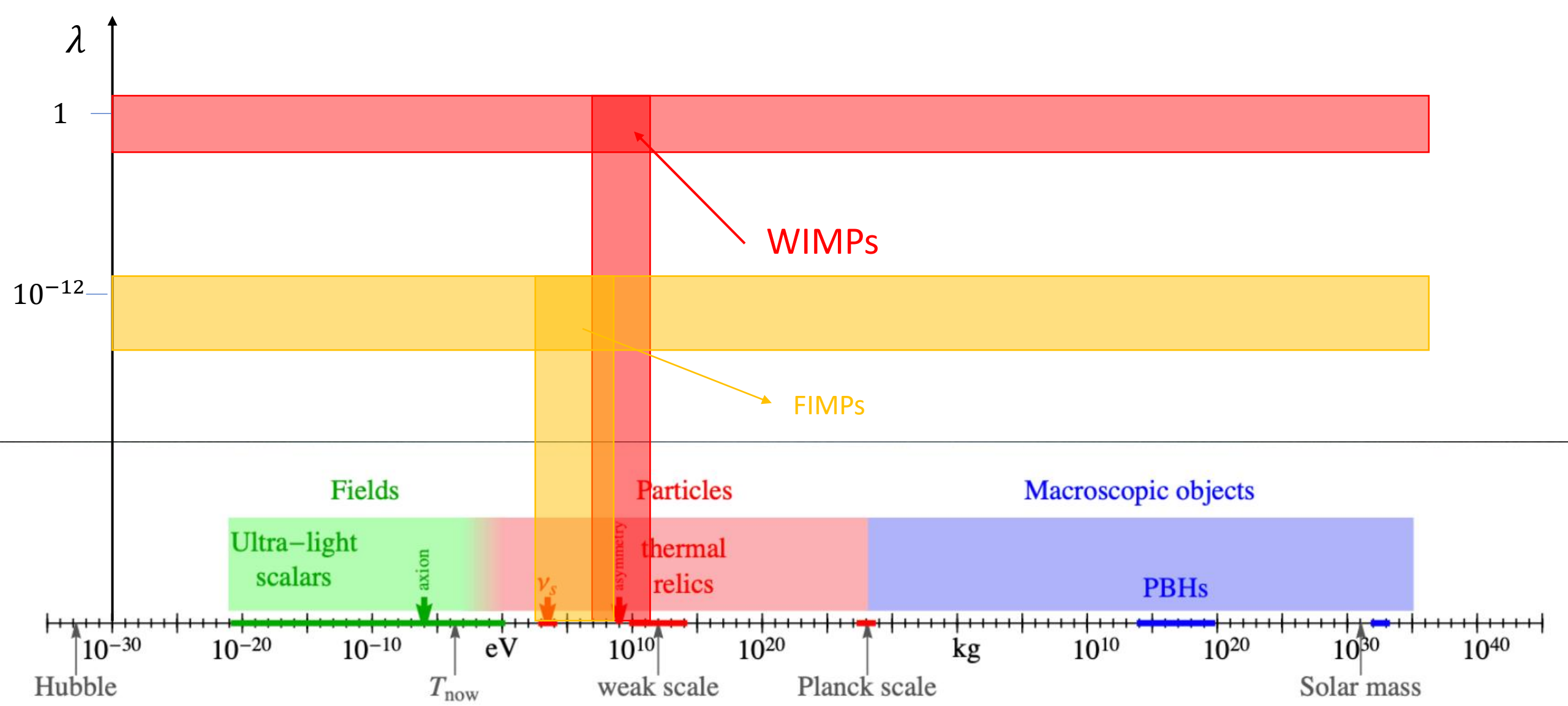
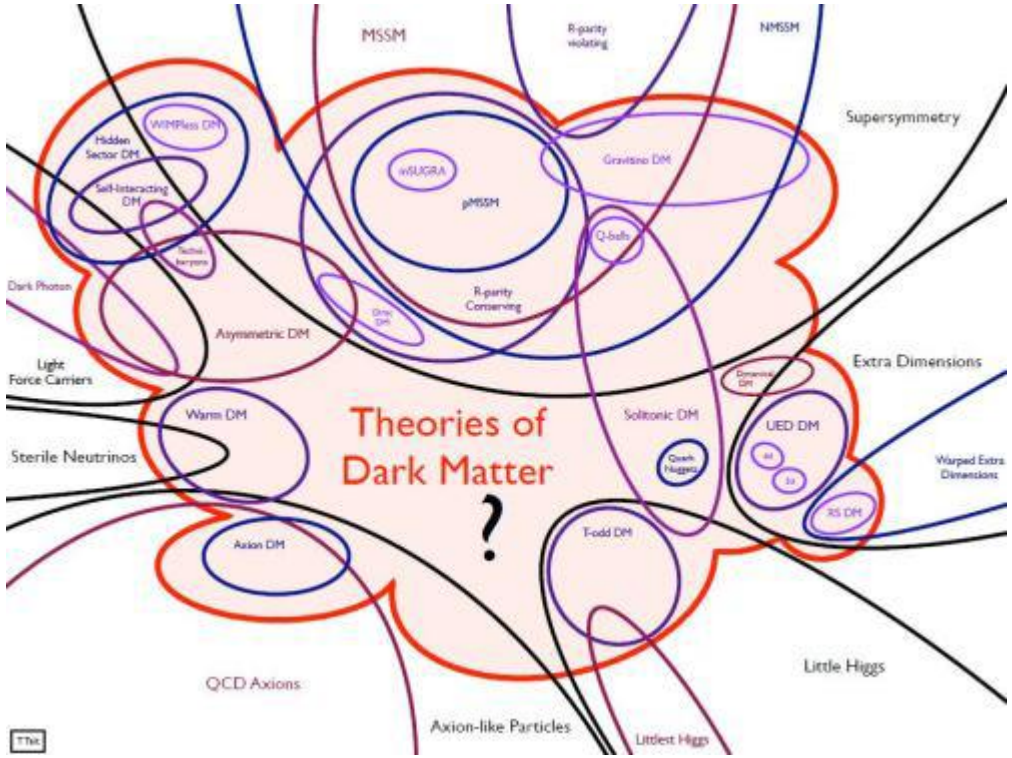
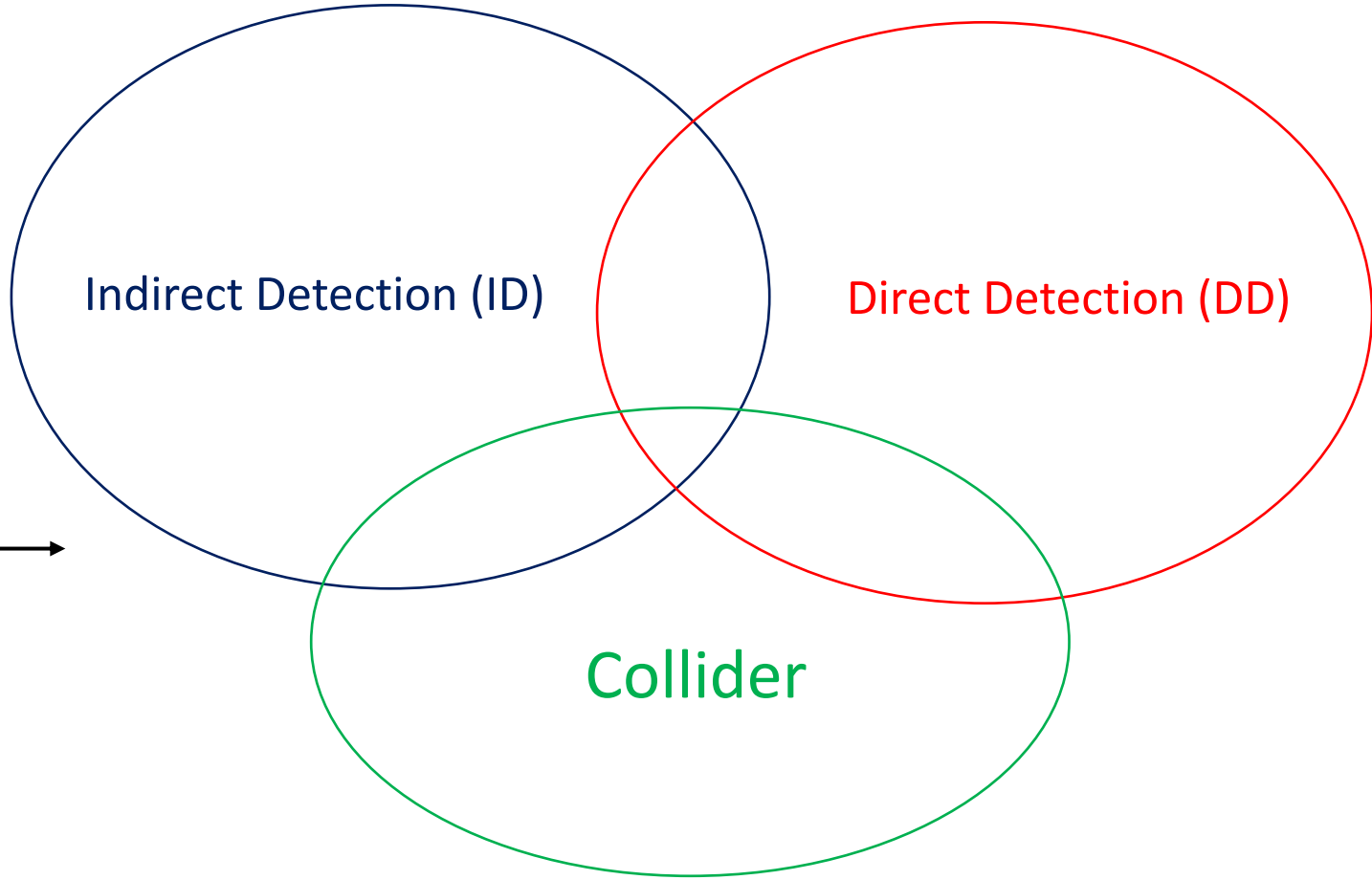


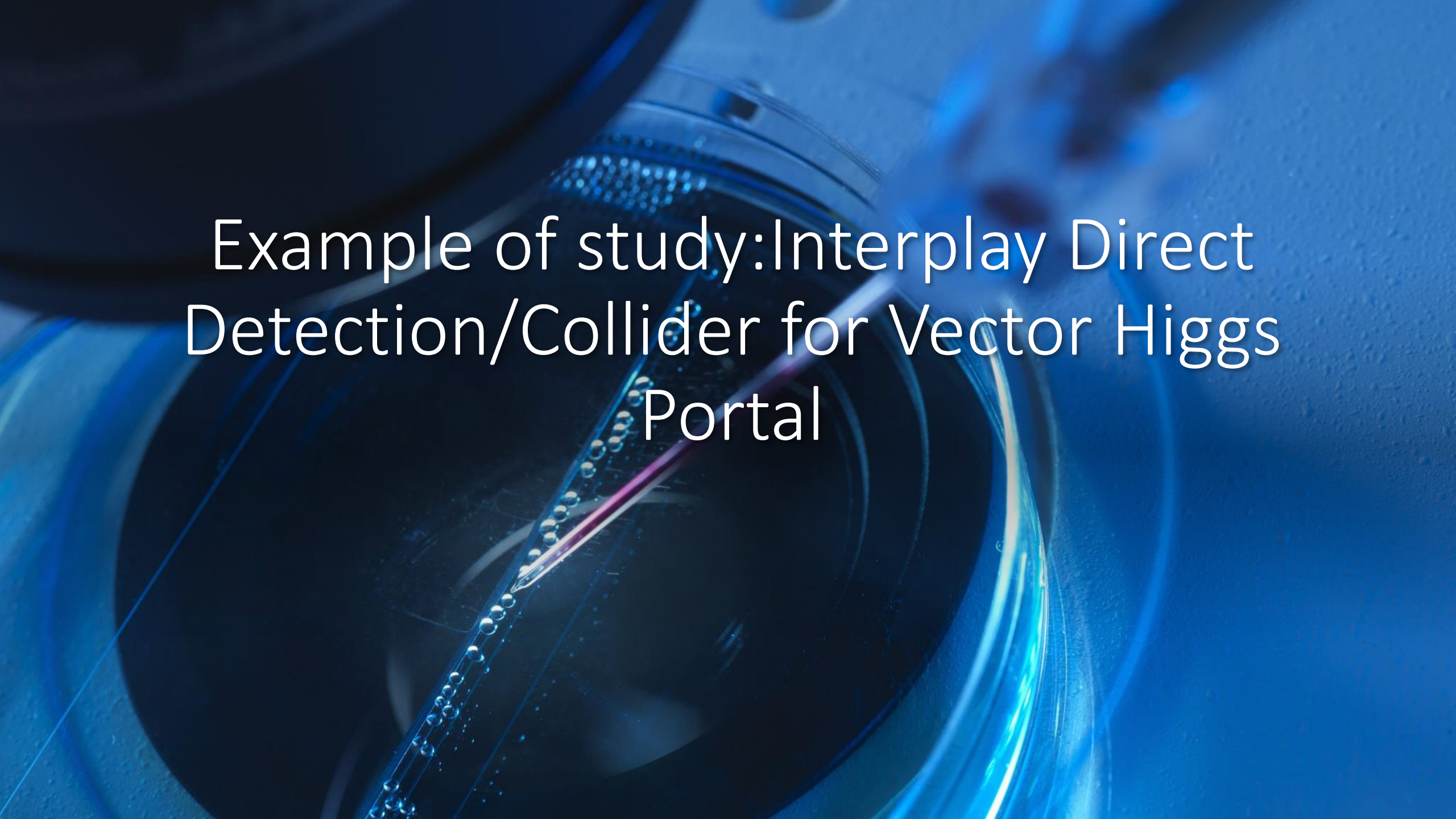
(Slide inspired from Marco Cirelli's talk at TAUP)

As a Dark Matter Physicist/Phenomenologist I see the following priorities:

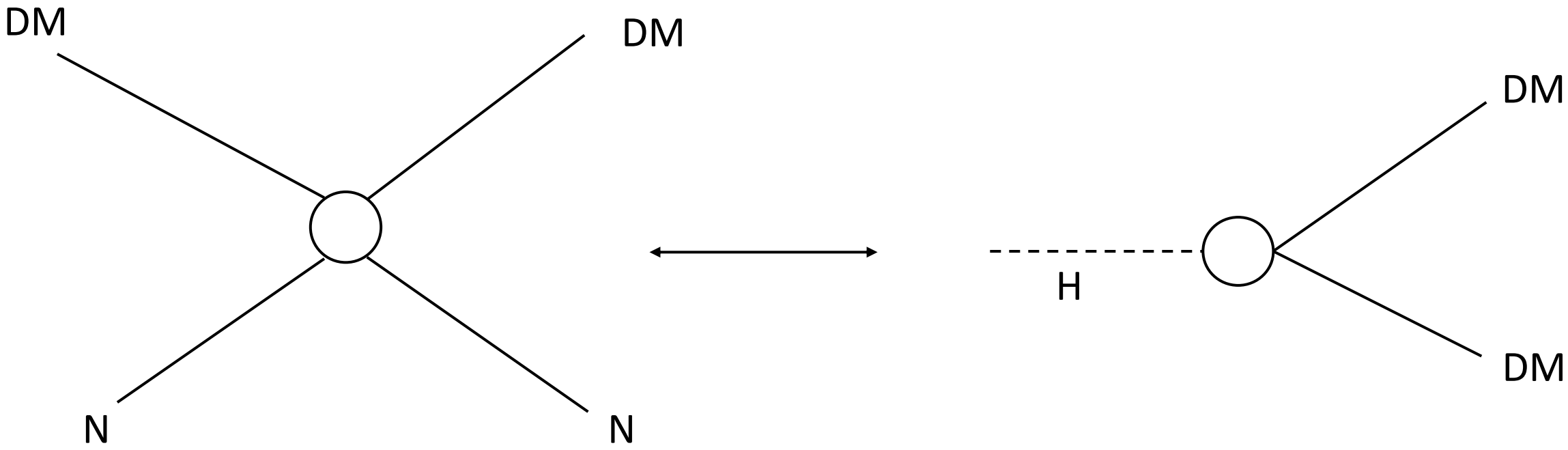
- Provide a viable theory interface between Theory and the experimental outcome.
- Better combine experimental information with DM production mechanism;
- Exploit complementarities with new experimental avenues, e.g. gravitational waves, PTA…


MSSM
R-parity violating
NMSSM
Supersymmetry
WIMPless DM
Hidden Sector DM
Self-Interacting DM
mSUGRA
pMSSM
Gravitino DM
Q-balls
Dark Photon
R-parity Conserving
Asymmetric DM
Light Force Carriers
Extra Dimensions
Warm DM
Theories of Dark Matter
?
Solitonic DM
UED DM
Sterile Neutrinos
Warped Extra Dimensions
Axion DM
T-odd DM
Little Higgs
QCD Axions
Axion-like Particles
Littlest Higgs


Indirect Detection (ID)
Direct Detection (DD)
Collider



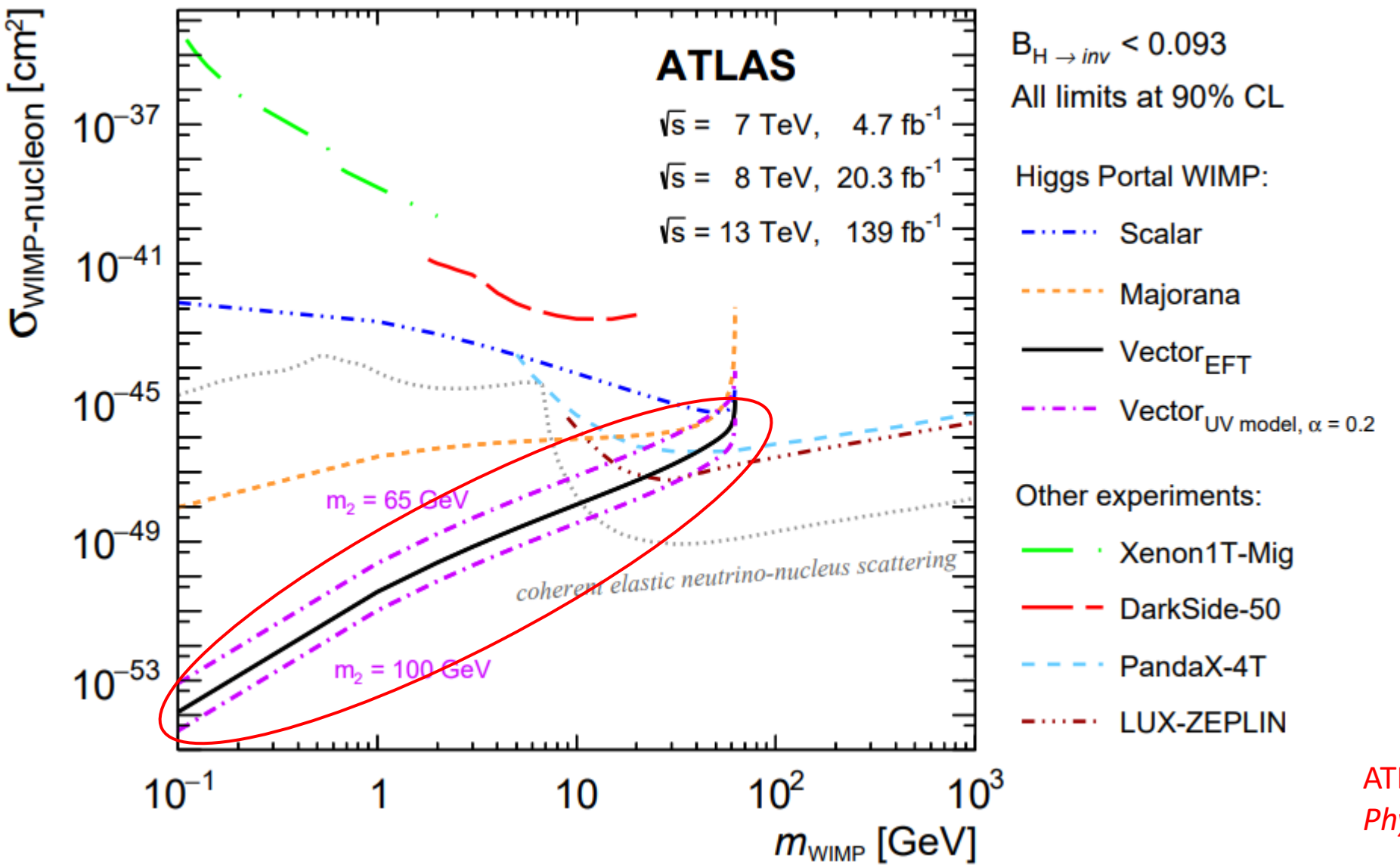
Example of study:Interplay Direct Detection/Collider for Vector Higgs Portal



$$\sigma^{SI}_{DM,N} = \frac{\mu^2_{DM,p}}{\pi M_H^4} \lambda^2_{HDMDM} \lambda^2_{HNN}$$

$$\sigma^{SI}_{DM,N} \propto Br(H \to DMDM)$$

LHC DD vs Invisible H width correlation plot



$B_{H \to inv} < 0.093$

All limits at 90% CL

Higgs Portal WIMP:

- Scalar
- Majorana
- $Vector_{EFT}$
- $Vector_{UV\ model,\ \alpha = 0.2}$

Other experiments:

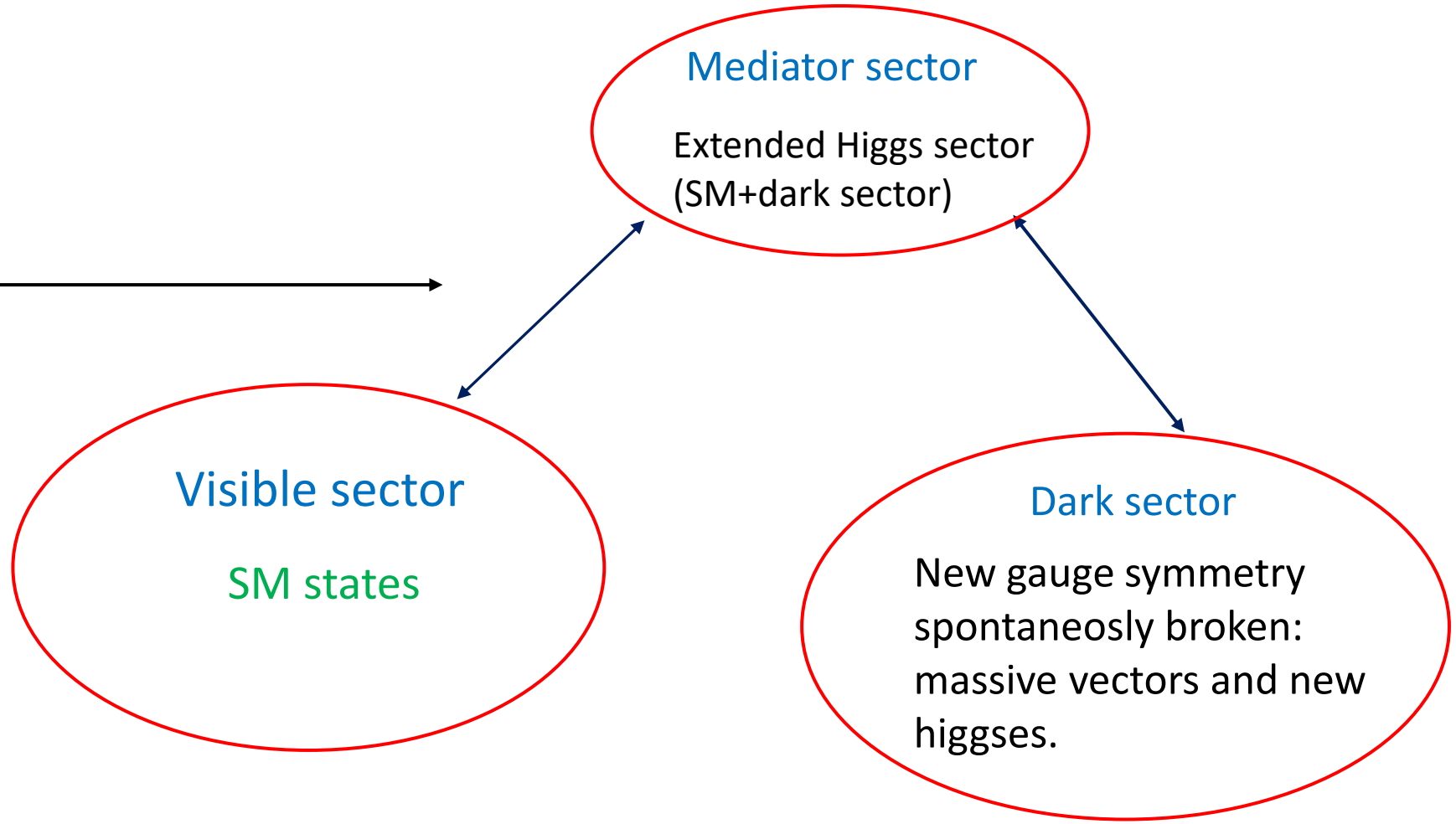
- Xenon1T-Mig
- DarkSide-50
- PandaX-4T
- LUX-ZEPLIN

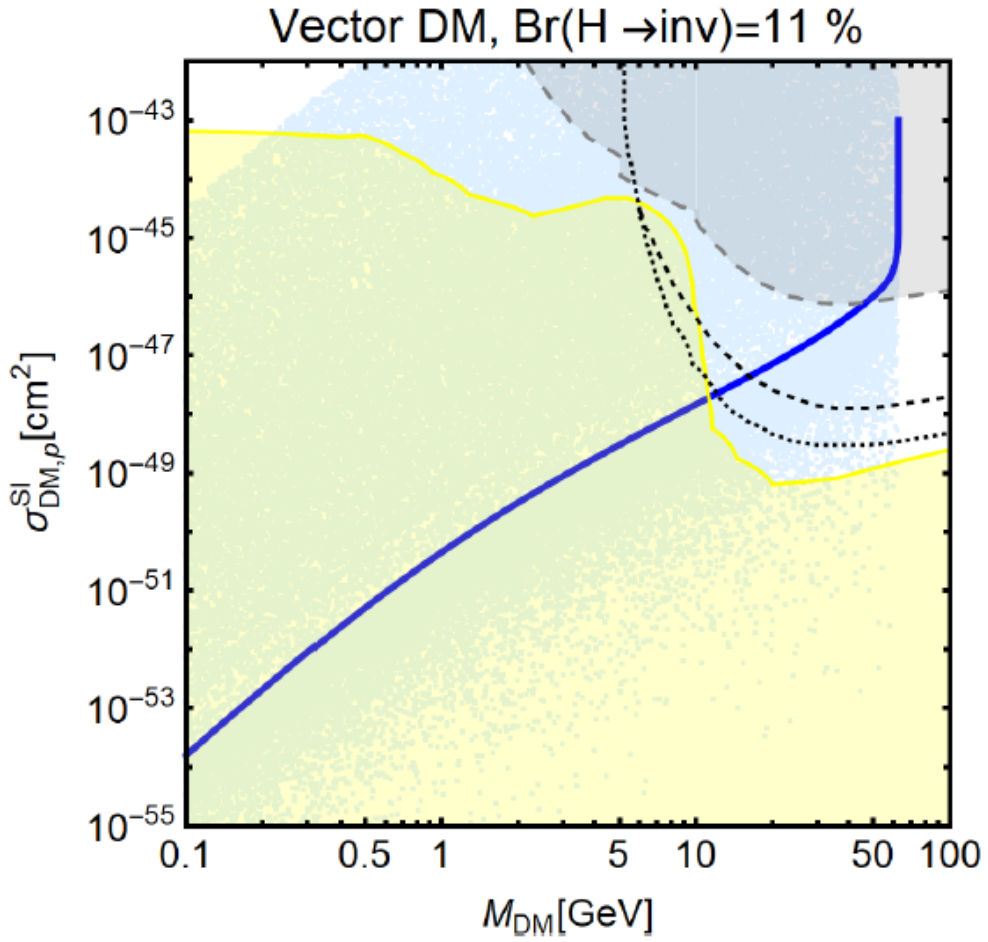
ATLAS Collaboration
Phys.Lett.B 842 (2023) 137963

Simplified vs Realistic Models

EFT Higgs portal

$$L \subset \lambda_{HVV} V^{\mu} V_{\mu} H H^{\dagger}$$





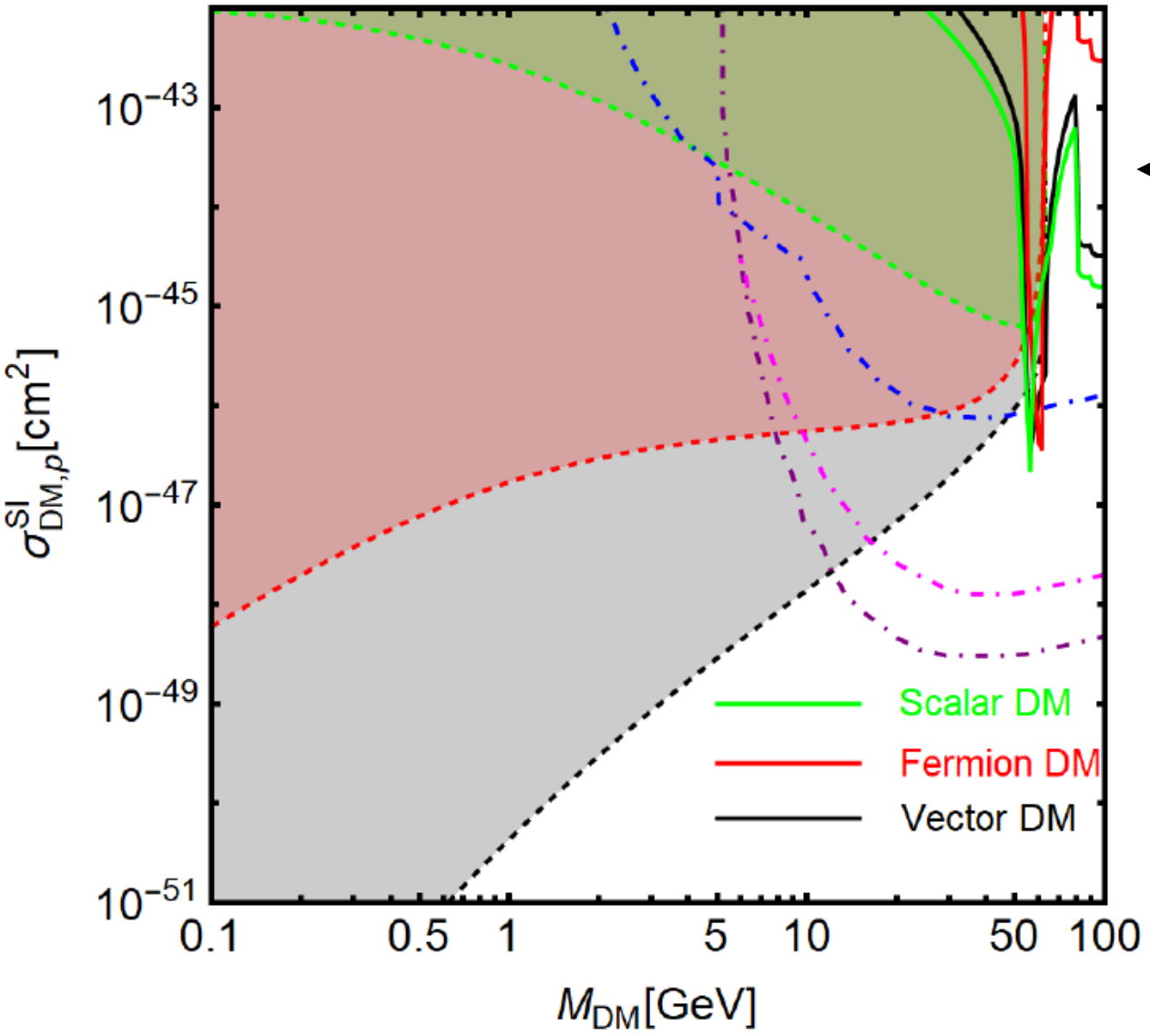
$$\frac{\sigma^{SI}_{UV}}{\sigma^{SI}_{EFT}} = \cos^2\theta\left(\frac{1}{M^2_{H_2}} - \frac{1}{M^2_{H_1}}\right)$$

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

G.A., A. Djouadi and M. Kado, Eur. Phys. J. C81 (2021) , 653

For similar studies see also: S. Baek et al. JHEP 05 (2013) 036
S. Baek et al. Phys. Rev. D90 (2014) 055015

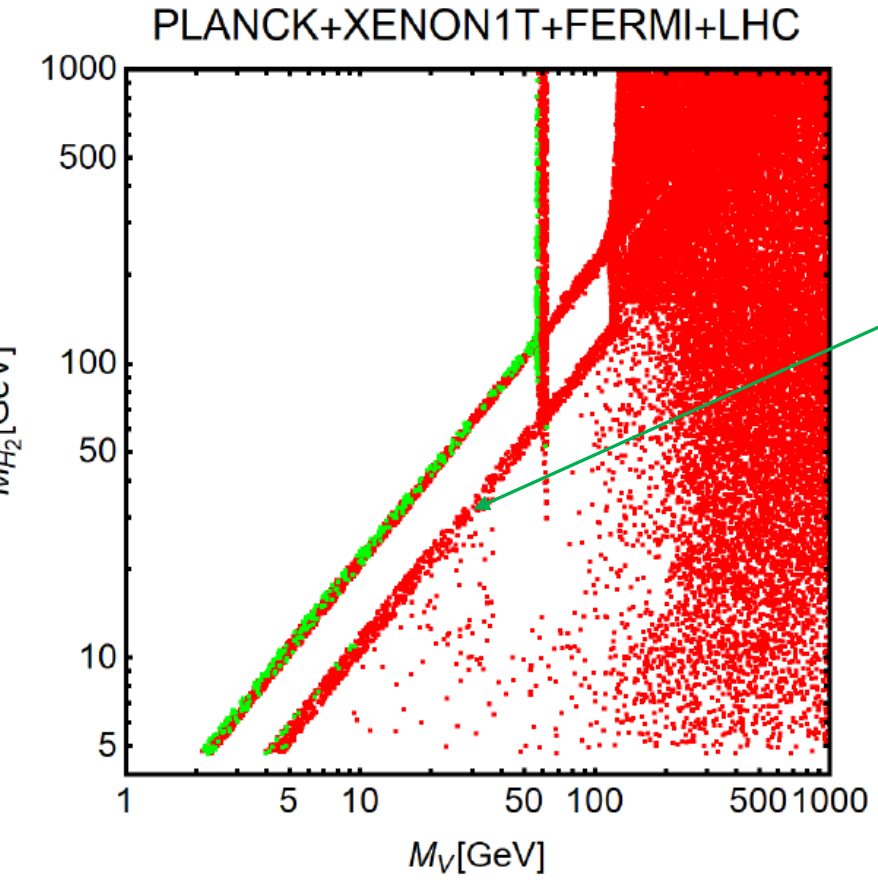
Impact of relic density on experimental constraints



Relic density regions according to WIMP paradigm are outside the interesting region.

Vector Dark Matter(dark U(1))

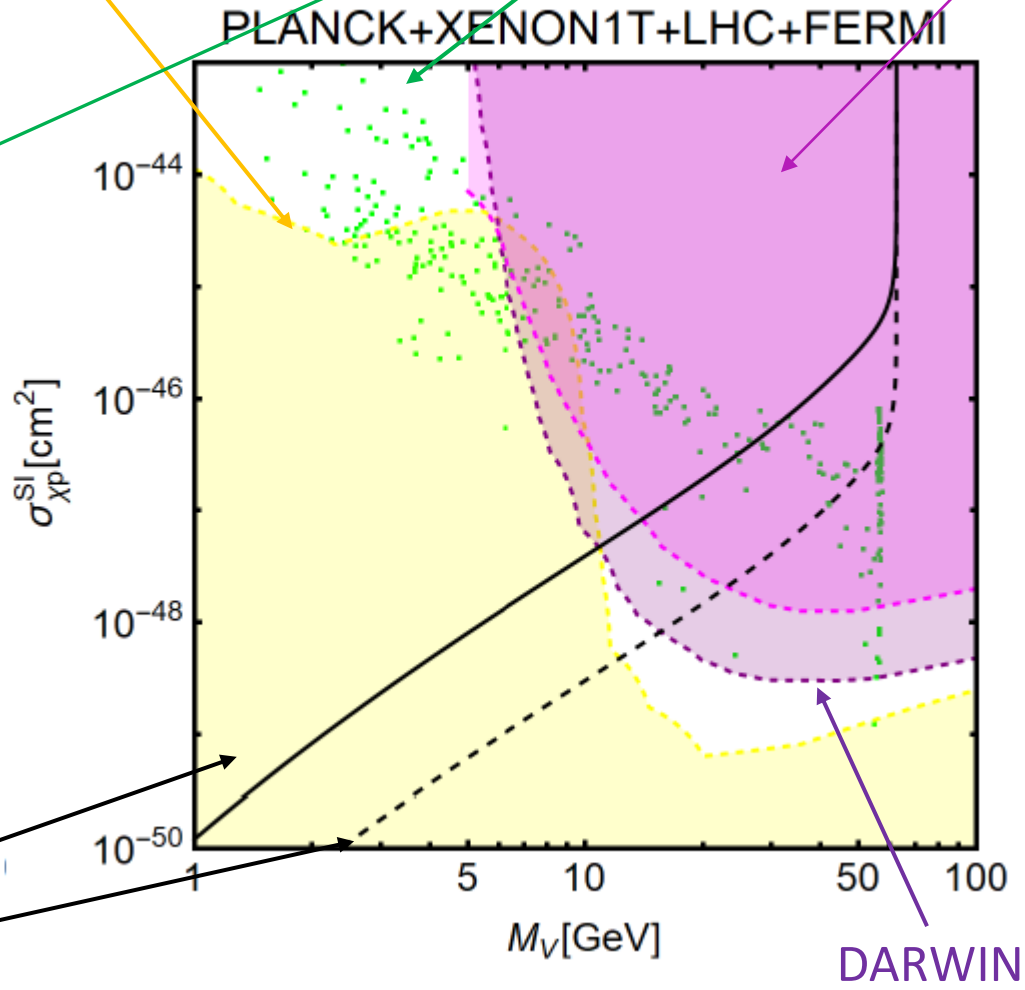
Light viable DM requires extra light degrees of freedom at the scale of the SM-like Higgs or below.



ν-floor

$2.5\% \leq Br(H \to inv) \leq 11\%$

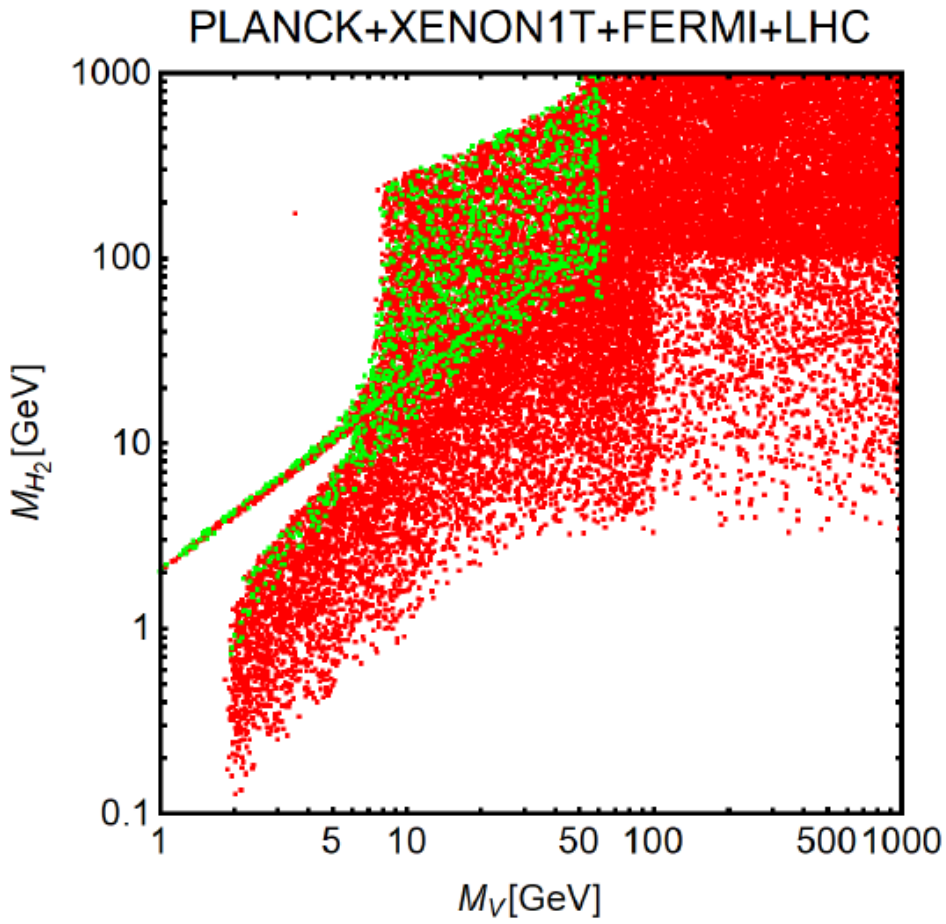
XENONnT

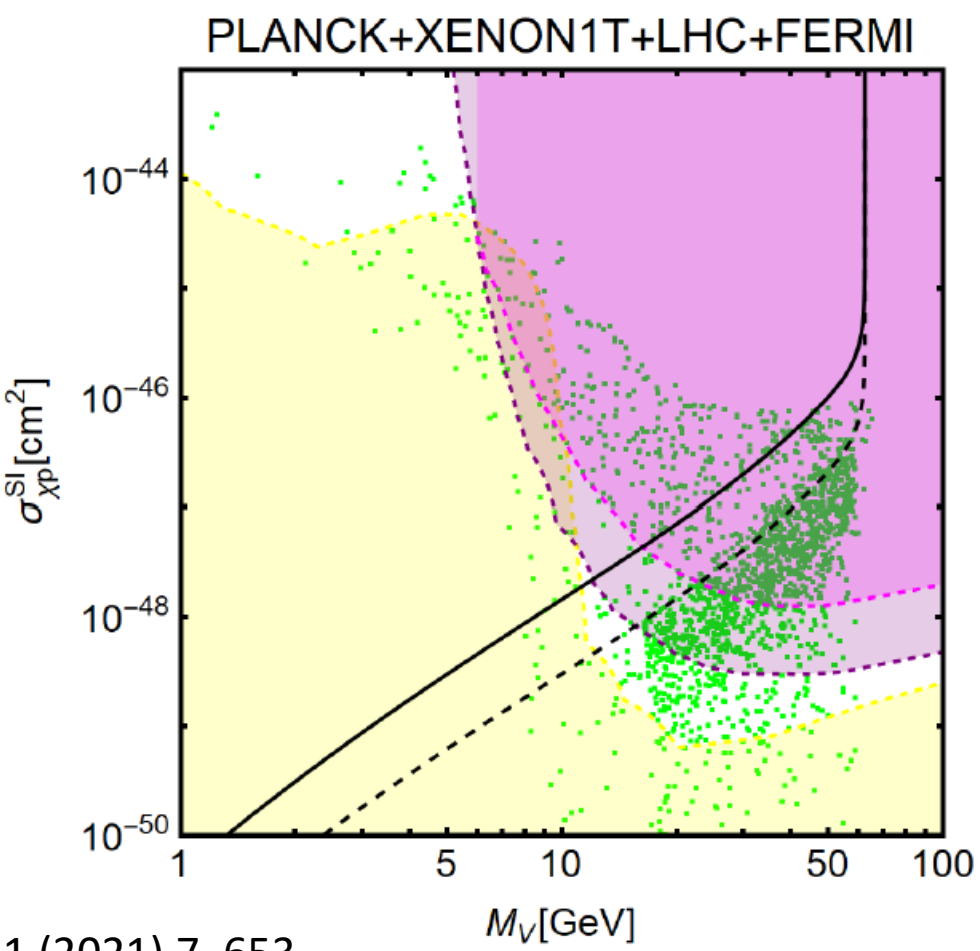


EFT Portal

DARWIN

Dark SU(3):V DM plus metastable V^3

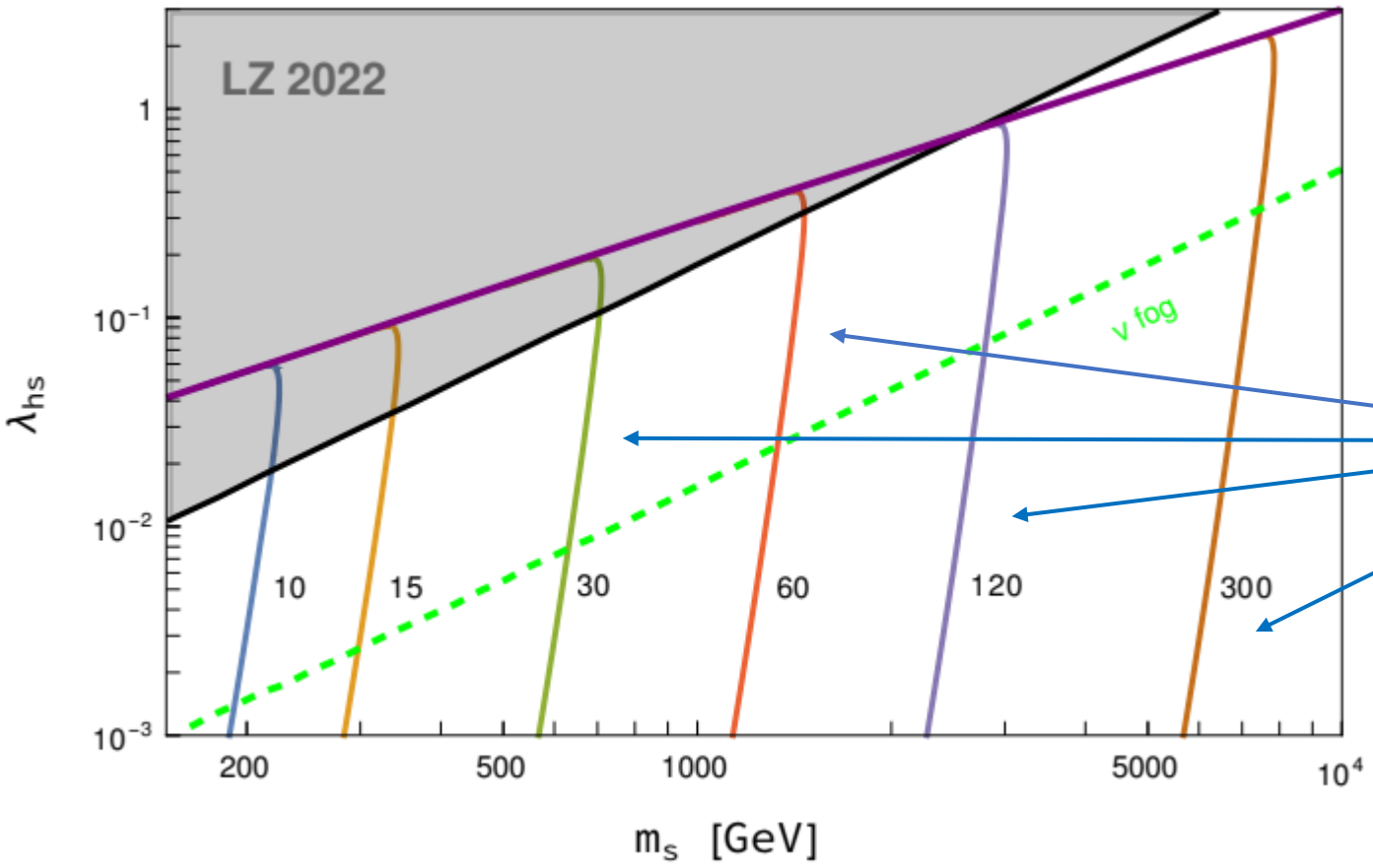




G.A., A. Djouadi, M. Kado, EPJ C81 (2021) 7, 653

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

Some new ideas for relic density:Freeze-in in Stronger Coupling



$$Y_{DM} = \frac{\sqrt{90}\cdot 45}{2^9\pi^7 g_*^{3/2}} \frac{\lambda_{hs}^2 M_{Pl}}{T_R} e^{-2m_s/T_R}$$

Reheating Temperature

C. Cosme, F. Costa, O. Lebedev
arXiv:2306.13061

Impact of modified cosmologies on parameter space

Freeze-before Early Matter Domination

$$\mathrm{Y}_{DM} = \frac{\mathrm{Y}_{DM,thermal}}{D}$$

Freeze-out during Early Matter Domination

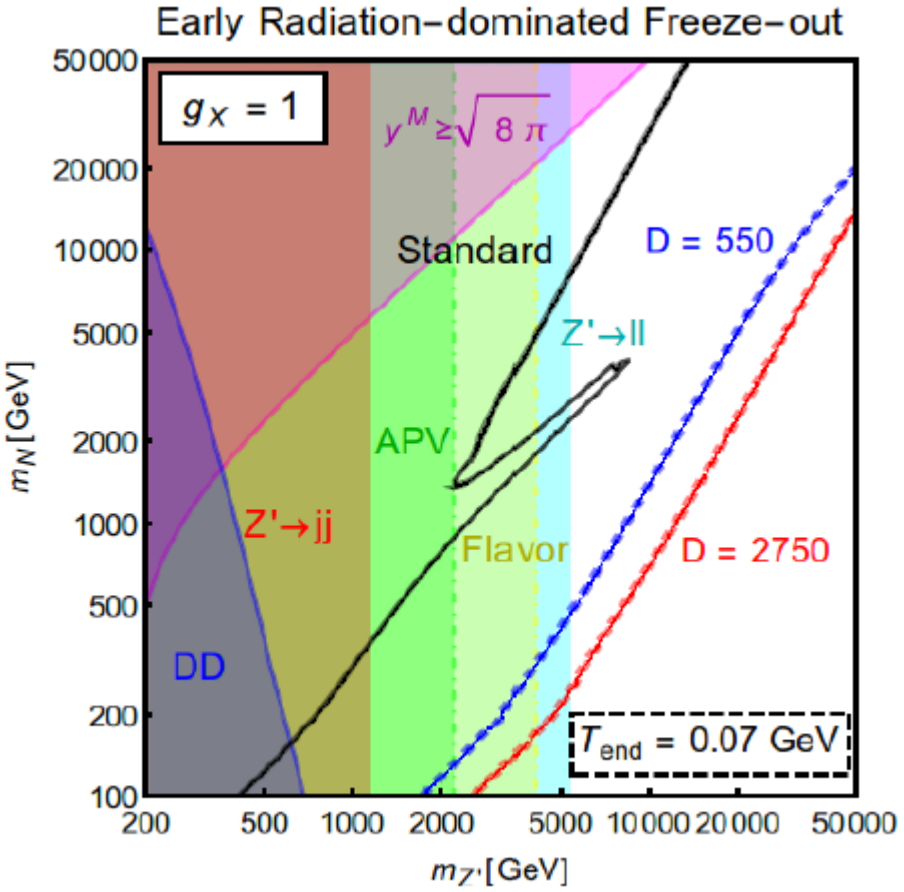
$$\rho_\phi \propto a^{-3} \qquad \mathrm{Y}_{DM} = \zeta Y_{DM,MD} \qquad Y_{DM,MD} = \frac{3}{2}\sqrt{\frac{45}{\pi}}\frac{\sqrt{g_*}}{g_{*,s}}\frac{x_f}{m_{DM}M_{pl}\langle\sigma v\rangle x_*^{1/2}}$$

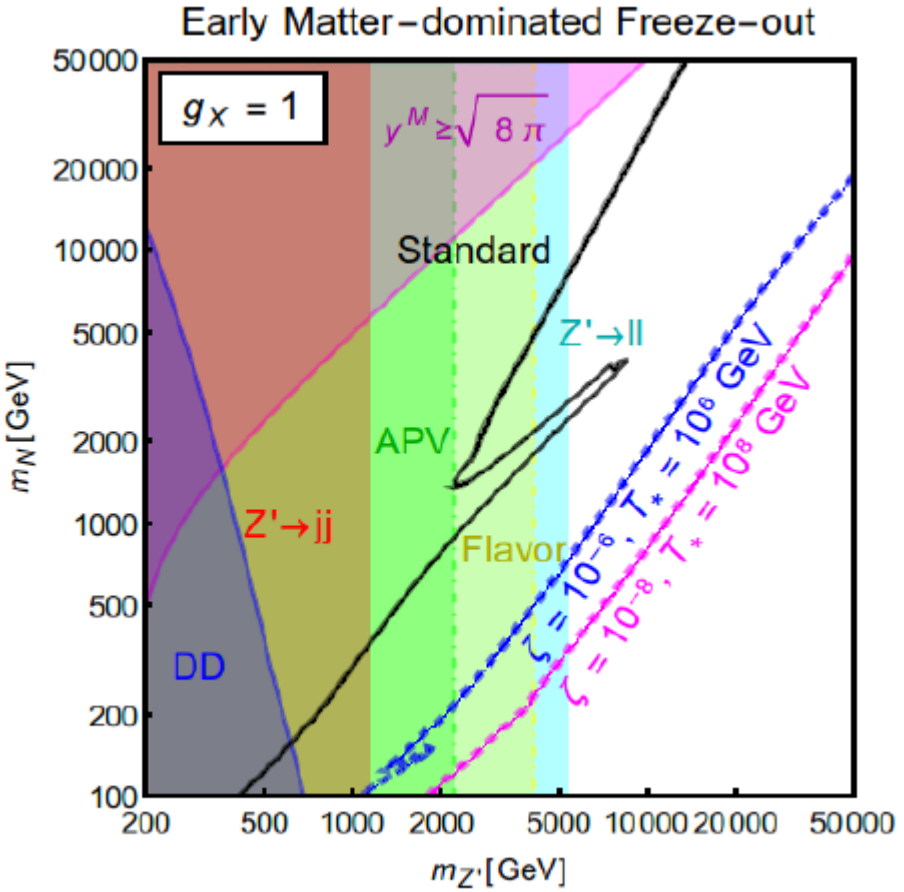
Phase of Faster Expansion

$$\rho_\phi \propto a^{-(4+n)} \qquad n \geq 2$$

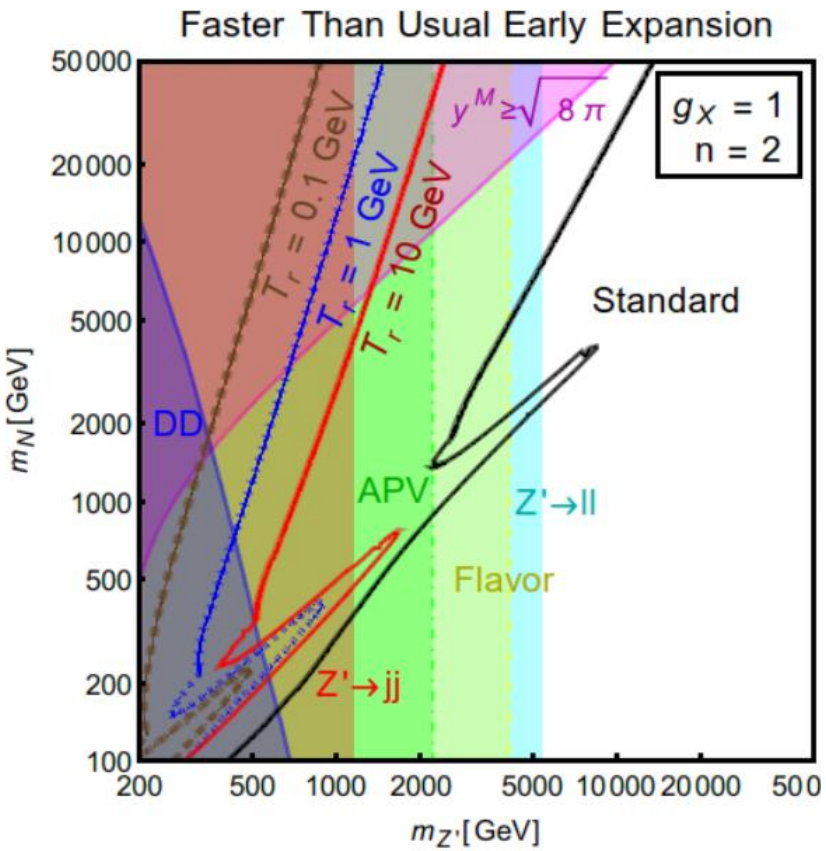
$$Y_{DM} \simeq \frac{x_r}{m_{DM}M_{pl}\langle\sigma v\rangle}\left[\frac{2}{x_f} + log\left(\frac{x}{x_f}\right)\right]^{-1} \qquad Y_{DM} \simeq \frac{x_r^{\frac{n}{2}}}{2m_{DM}M_{pl}\langle\sigma v\rangle}\left[x_f^{\frac{n}{2}-2} + \frac{x^{\frac{n}{2}-1}}{n-1}\right]^{-1}$$

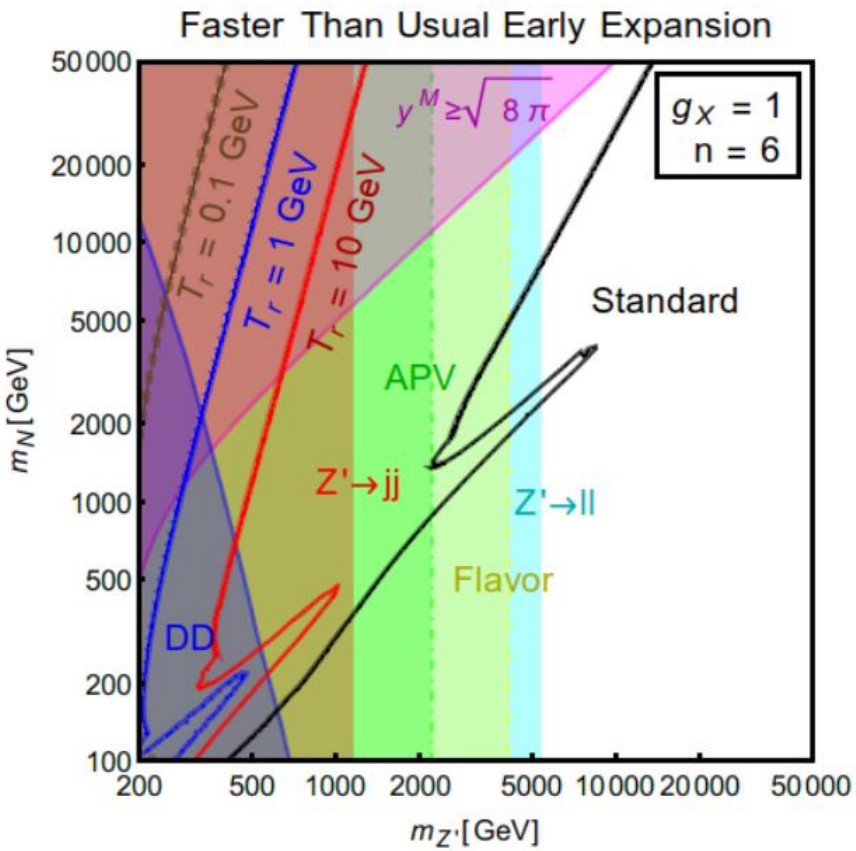
Case of study: B-L extension of the Standard Model

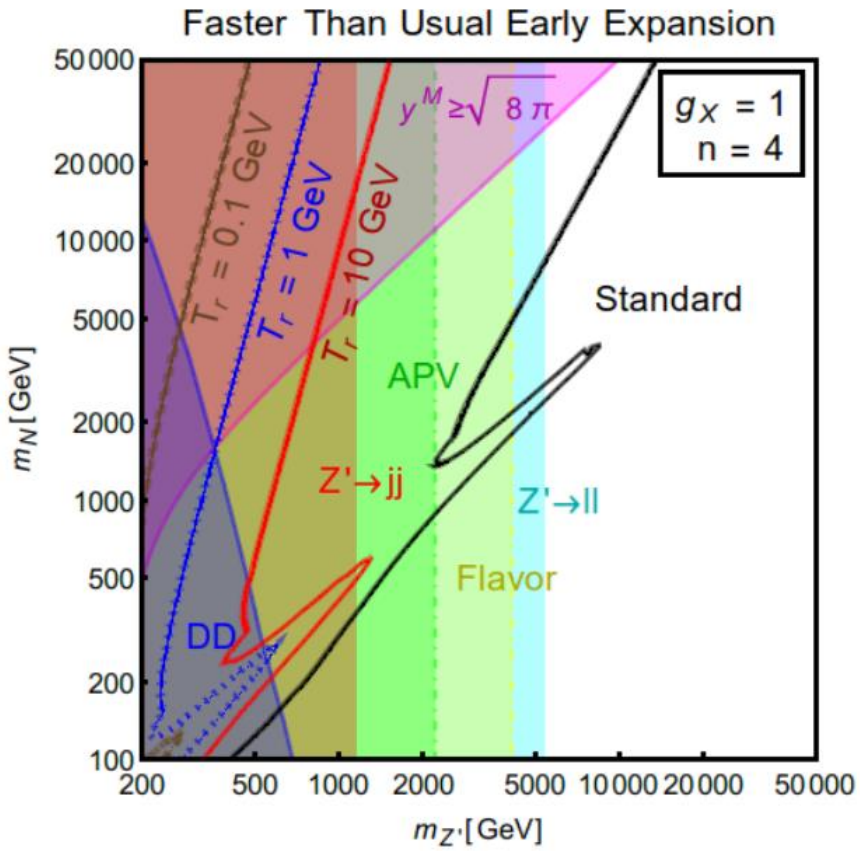




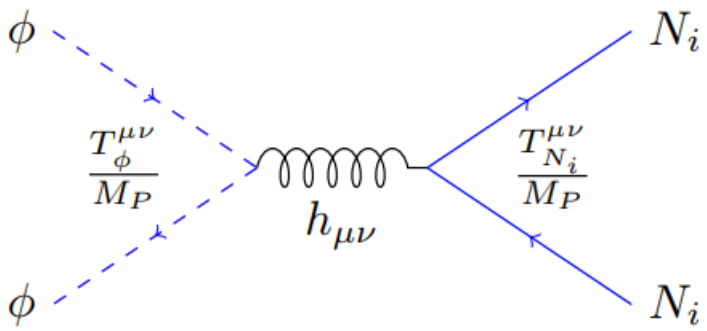
M. Campos, D. Gogollo, M. Lindner T. Melo, F. S. Queiroz JHEP08 (2017) 092
G.A., S. Profumo, F. S. Queiroz, C. Siquera JCAP12 (2020) 030
G.A., J. P. Neto, F. S. Queiroz, C. Siquera PRD105 (2022) 035016

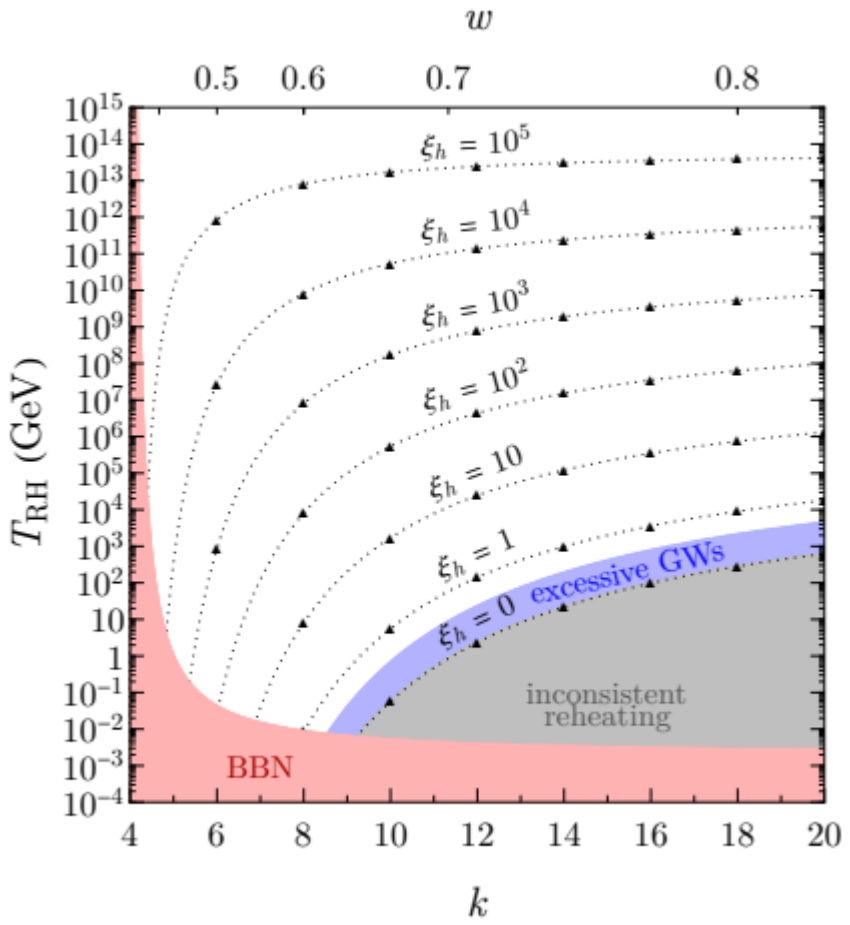

Faster Than Usual Early Expansion
g_X = 1
n = 2
$y^M \geq \sqrt{8\pi}$
T_r = 0.1 GeV
T_r = 1 GeV
T_r = 10 GeV
Standard
DD
APV
Z'→ll
Flavor
Z'→jj
m_N[GeV]
$m_{Z'}$[GeV]
50000
20000
10000
5000
2000
1000
500
200
100
200
500
1000
2000
5000
10000
20000
50000

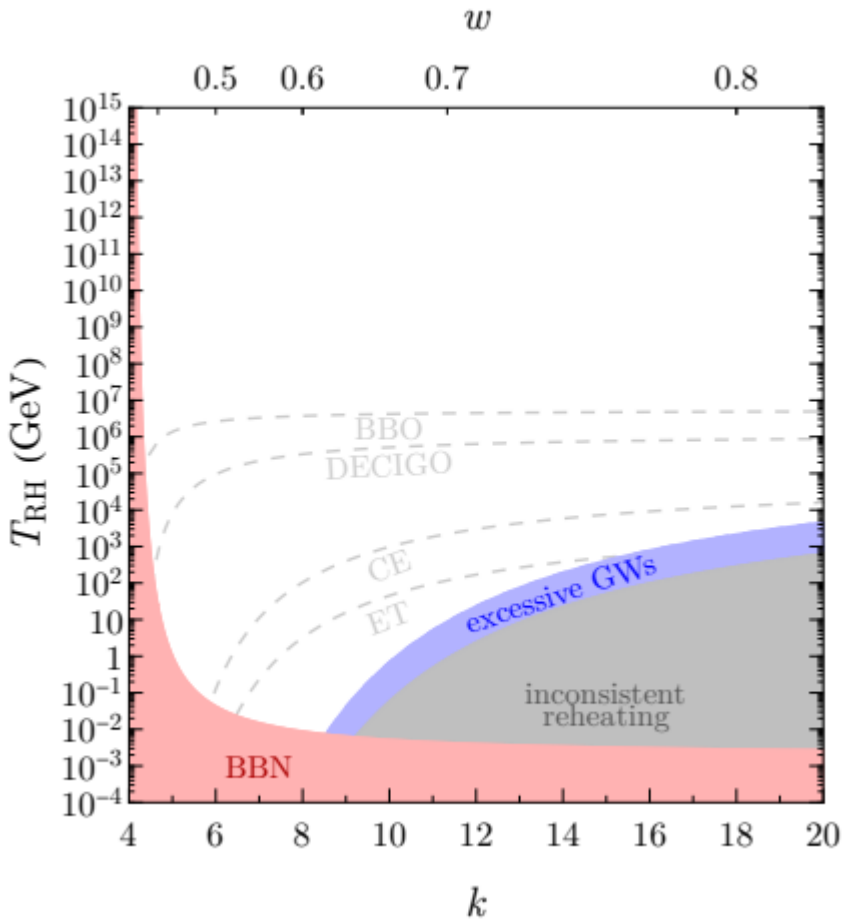

Faster Than Usual Early Expansion
g_X = 1
n = 6
$y^M \geq \sqrt{8\pi}$
T_r = 0.1 GeV
T_r = 1 GeV
T_r = 10 GeV
Standard
APV
Z'→jj
Z'→ll
Flavor
DD
m_N[GeV]
$m_{Z'}$[GeV]
50000
20000
10000
5000
2000
1000
500
200
100
200
500
1000
2000
5000
10000
20000
50000


Faster Than Usual Early Expansion
g_X = 1
n = 4
$y^M \geq \sqrt{8\pi}$
T_r = 0.1 GeV
T_r = 1 GeV
T_r = 10 GeV
Standard
APV
Z'→jj
Z'→ll
Flavor
DD
m_N[GeV]
$m_{Z'}$[GeV]
50000
20000
10000
5000
2000
1000
500
200
100
200
500
1000
2000
5000
10000
20000
50000

Dark Matter and Gravitational Waves





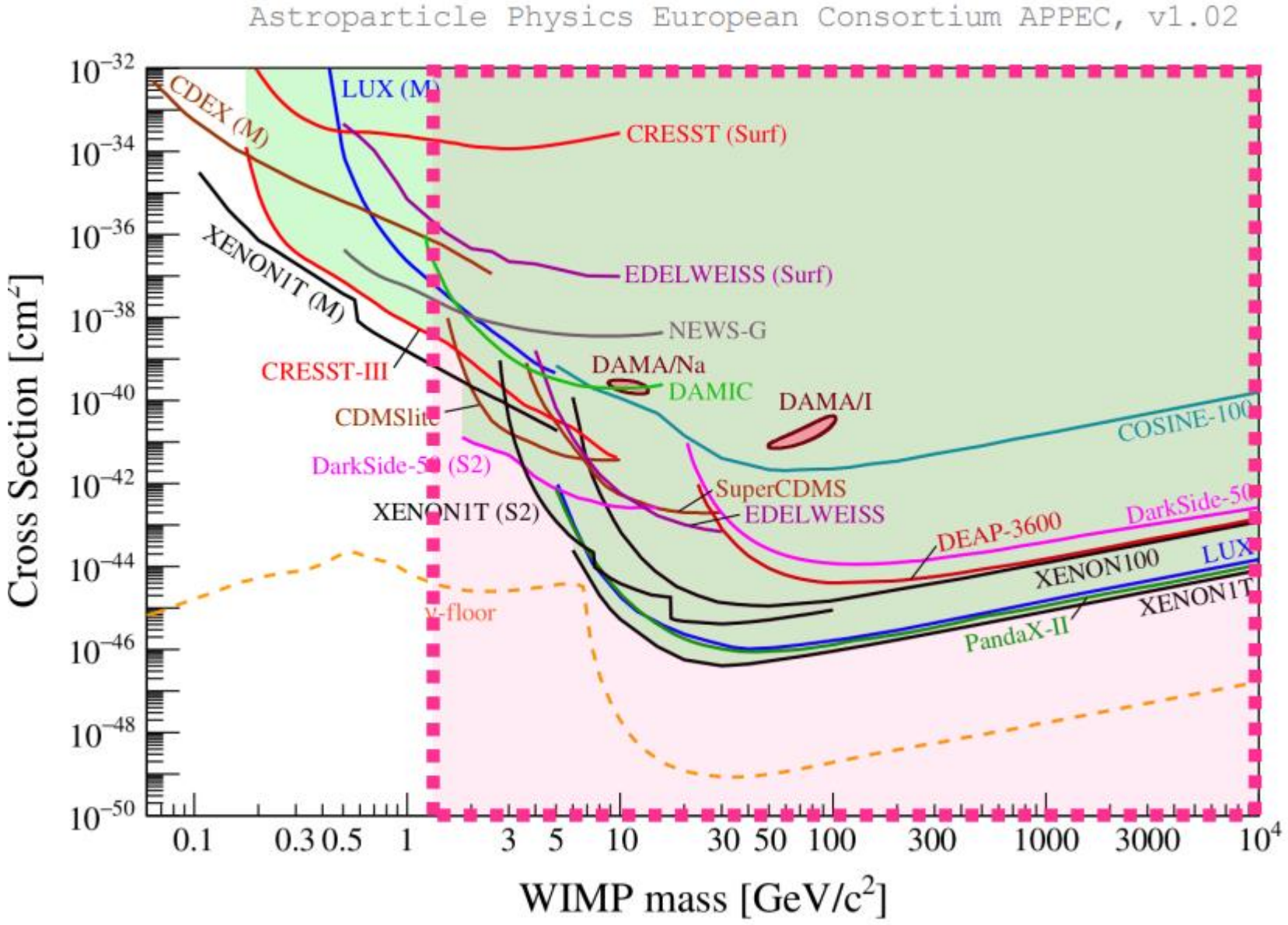


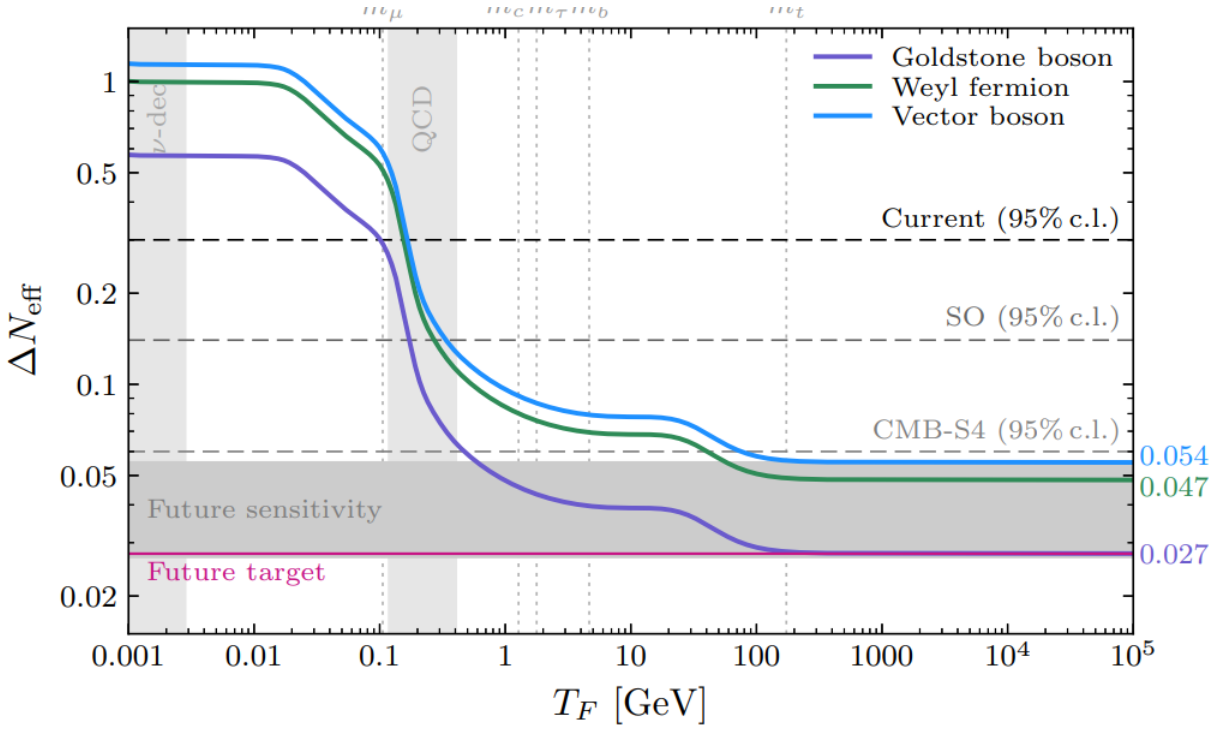
B. Barman, S. Clery, Y. Mambrini and K. Olive
JHEP 12 (2022) 072

Back up

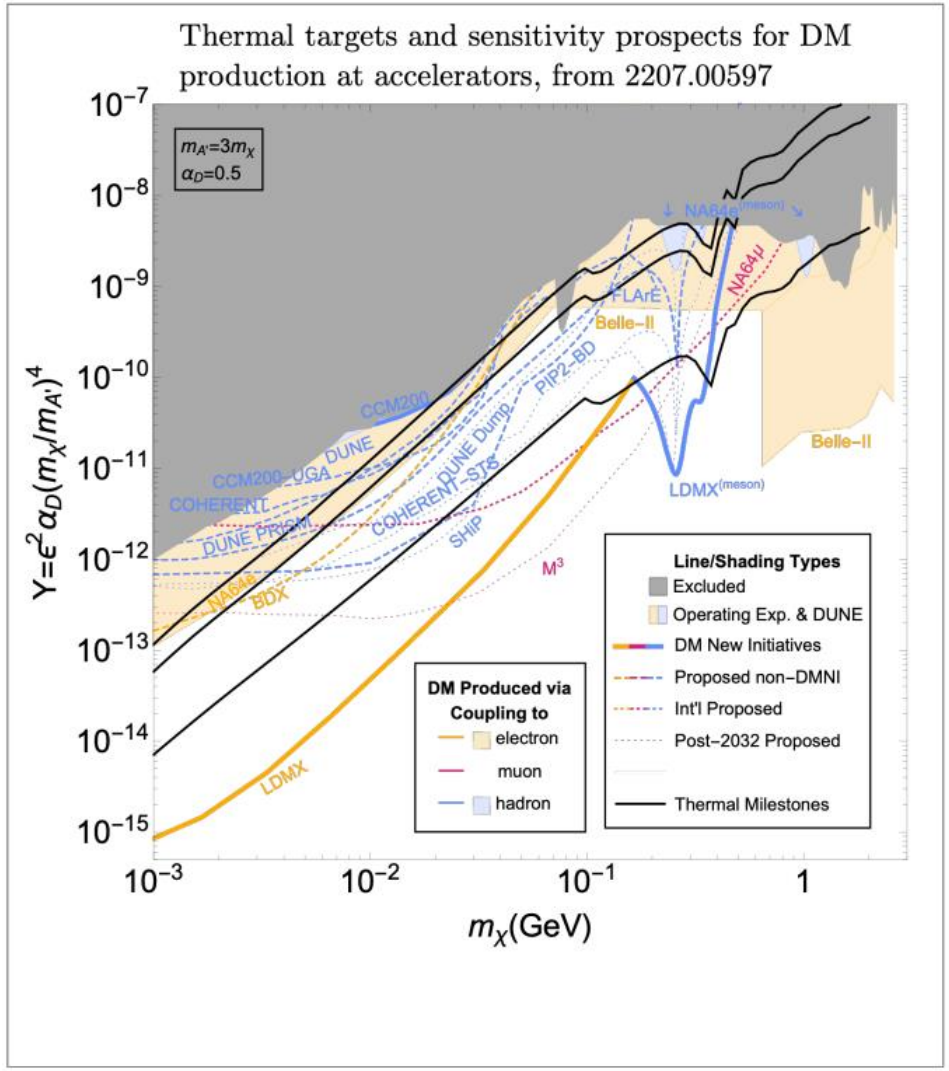
Great experimental effort to cover the light DM region.

Need of increase theoretical support?





C. Dvorkin et al. arXiv:2203.07943



arXiv:2305.01715