# *Cosmology of t-channel DM models*

Goals of the section

- Provide a general overview of the cosmology of t-channel models and point to the relevant literature

- Give overview of production mechanisms

- Give overview of main searches for:

- Direct detection

- Indirect detection

- Illustrate cosmological bounds for the most relevant models of t-channel (minimal model, universal couplings, leptophilic, …)

- From parameter space available define viable benchmarks for collider searches

Contributors: C. Arina (section coordinator), M. Becker, E. Coppello, J. Harz, J. Heisig, A. Ibarra, S. Khalil, M. Kirtiman, M. Kraemer, L. Lopez-Honorez, L. Panizzi, D. Sengupta, Y. Sheng, S. Tentori

Dark Matter production in the early universe


Relic abundance via freeze-out Standard mechanism

Planck experiment sets $\Omega h^2 = 0.12$
[arXiv:1807.06209]

LO processes for colored mediators

DM annihilation

$\propto \lambda_\varphi^4$

coannihilation (compressed spectrum)

$\propto \alpha_s^2$
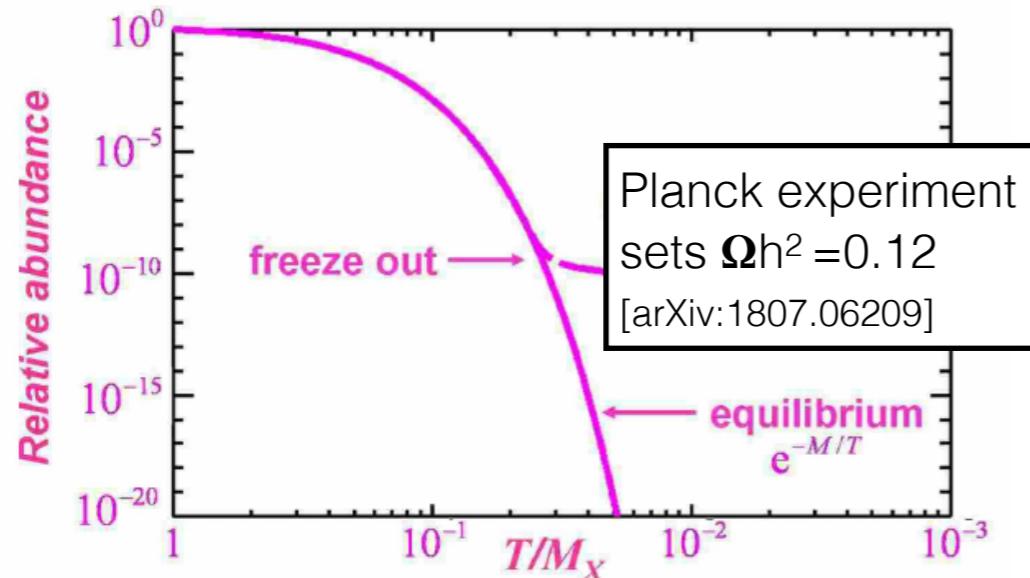
$\propto \lambda_\varphi^2 \alpha_s$
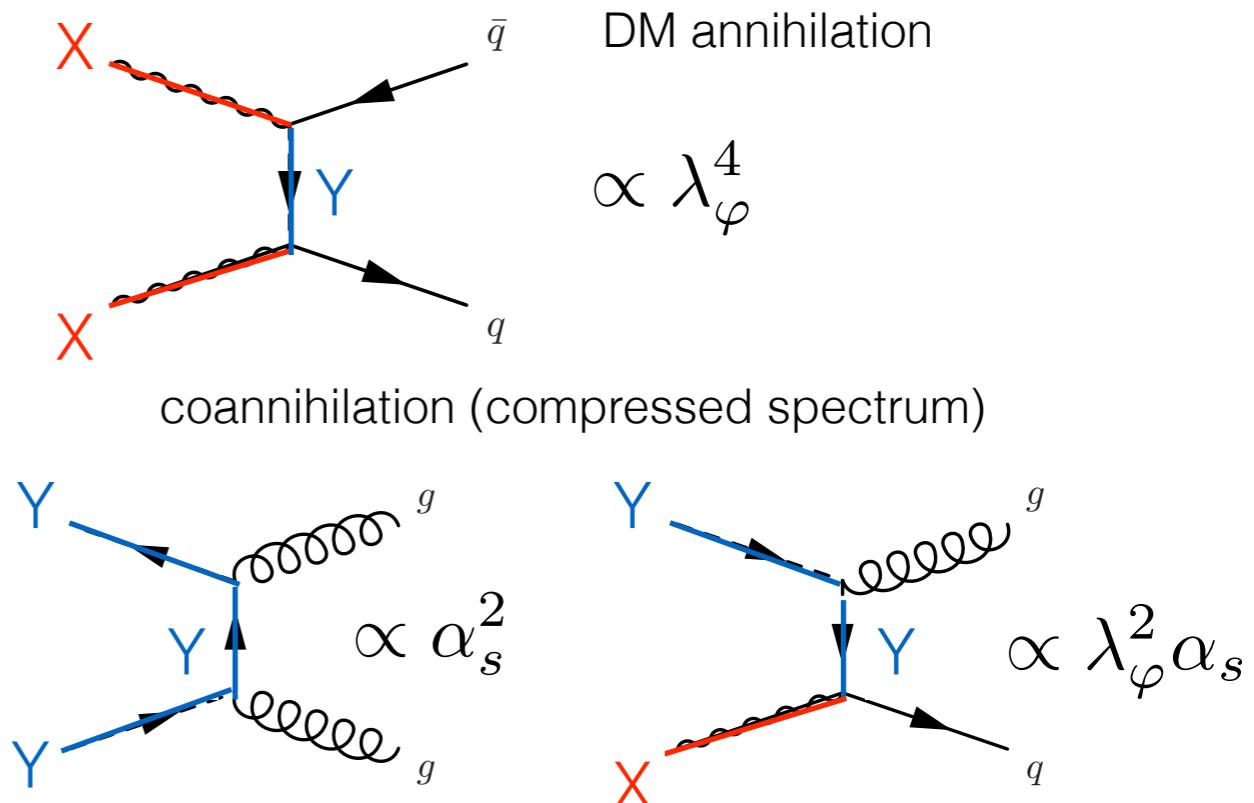
Non-colored mediators (e.g. leptophilic models) q->l, g-> SU(2)XU(1) gauge bosons

- FIMPs, SuperWIMPs, etc.. —> relevant as they provide LLPs signatures
- achieve relic density via other mechanisms such as freeze-in or decay of heavy species (non-thermal scenarios)
- Main alternative to freeze-out are considered

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Dark Matter production in the early universe

Sommerfeld enhancement + bound states are taken into account in the benchmark scenarios and contribute to the freeze-out picture

Example of Feynman diagram contributing to radiative capture into bound states
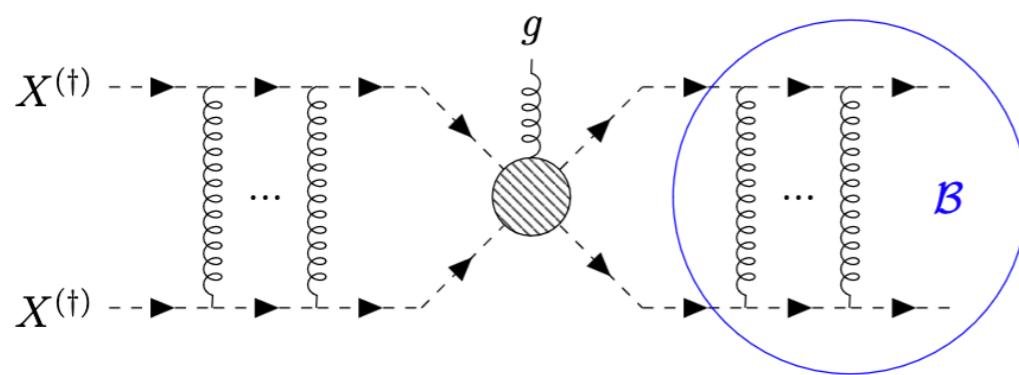

From arXiv:2203.04326, Becker et al.
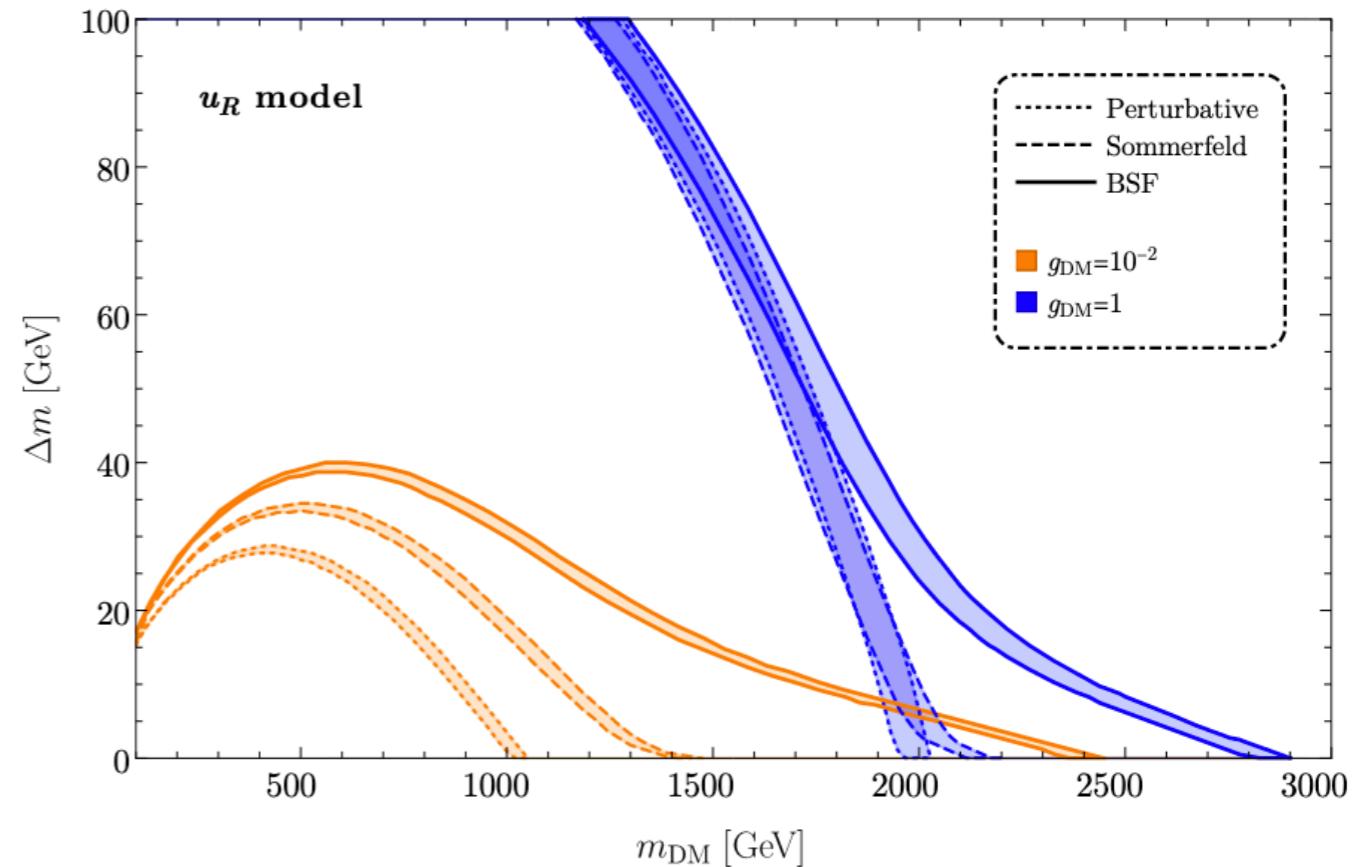
Non perturbative corrections are QCD corrections, so rather universal and are relevant when e.g. the X and Y are close in mass (Sommerfeld)

Dark Matter direct searches

Loop-induced processes for non-colored mediators

Based on works by A. Ibarra and its collaborators

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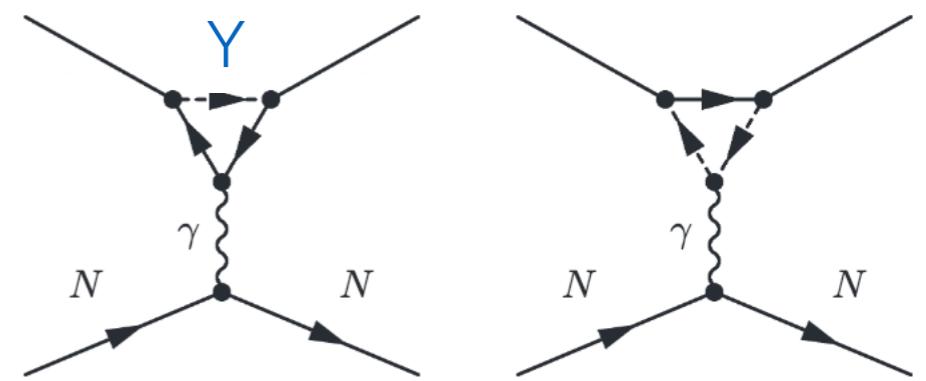
Dark Matter direct searches

*Direct detection
(Elastic scattering DM-nucleon)*
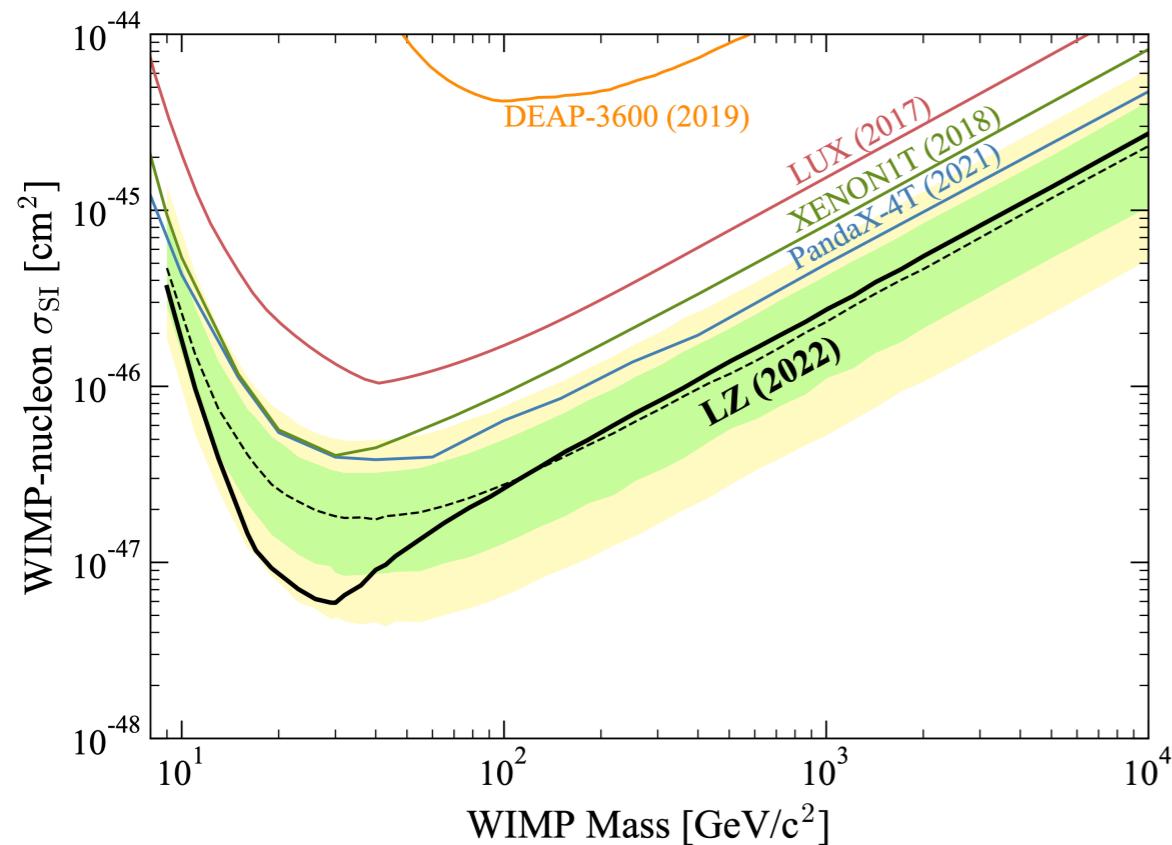
LO and/or NLO/loop processes for colored mediators
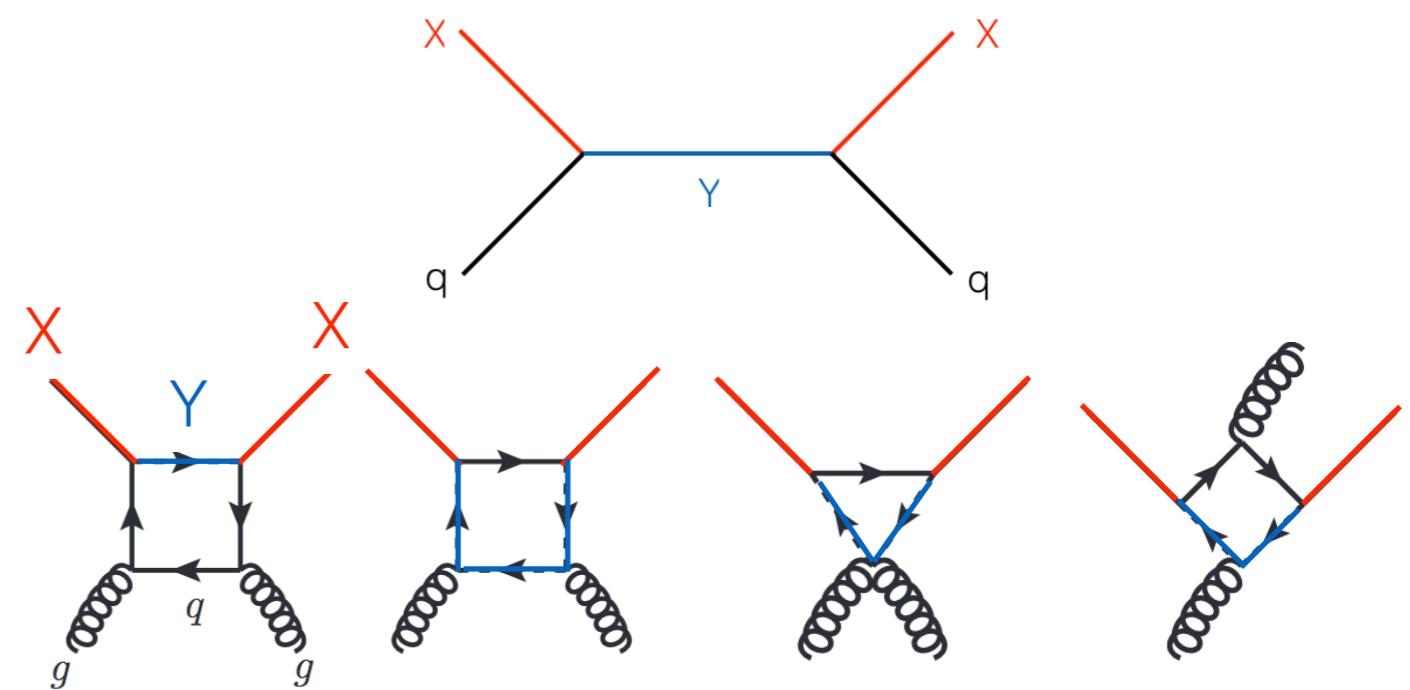
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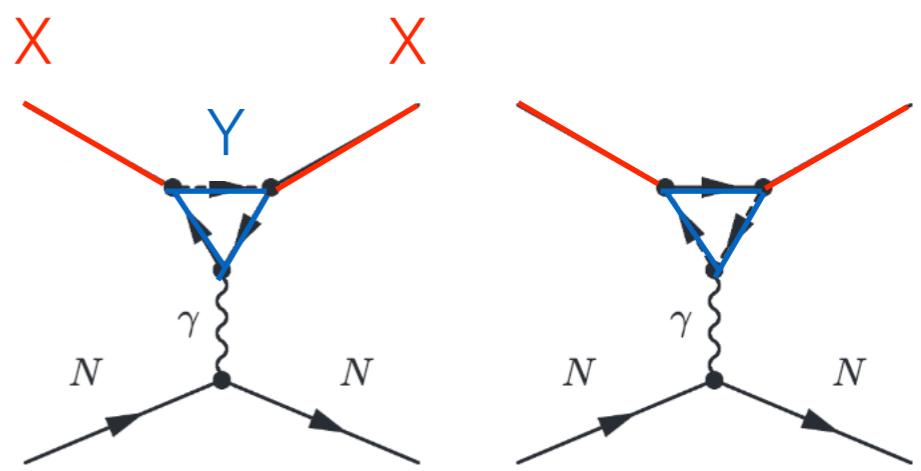
Dark Matter indirect searches

Indirect detection: annihilation of dark matter into SM particles in the halo at present time

- In many models LO annihilation is at least p-wave suppressed (Majorana, scalar DM)
- NLO processes uplift the suppression and produce a sharp feature in the gamma-ray energy spectrum
- Main signal used to compare with indirect detection searches

Virtual internal bremsstrahlung (VIB)

Loop-induced diphotons

C. Arina, B. Fuks and L. Mantani, arXiv:2001.05024 [hep-ph]
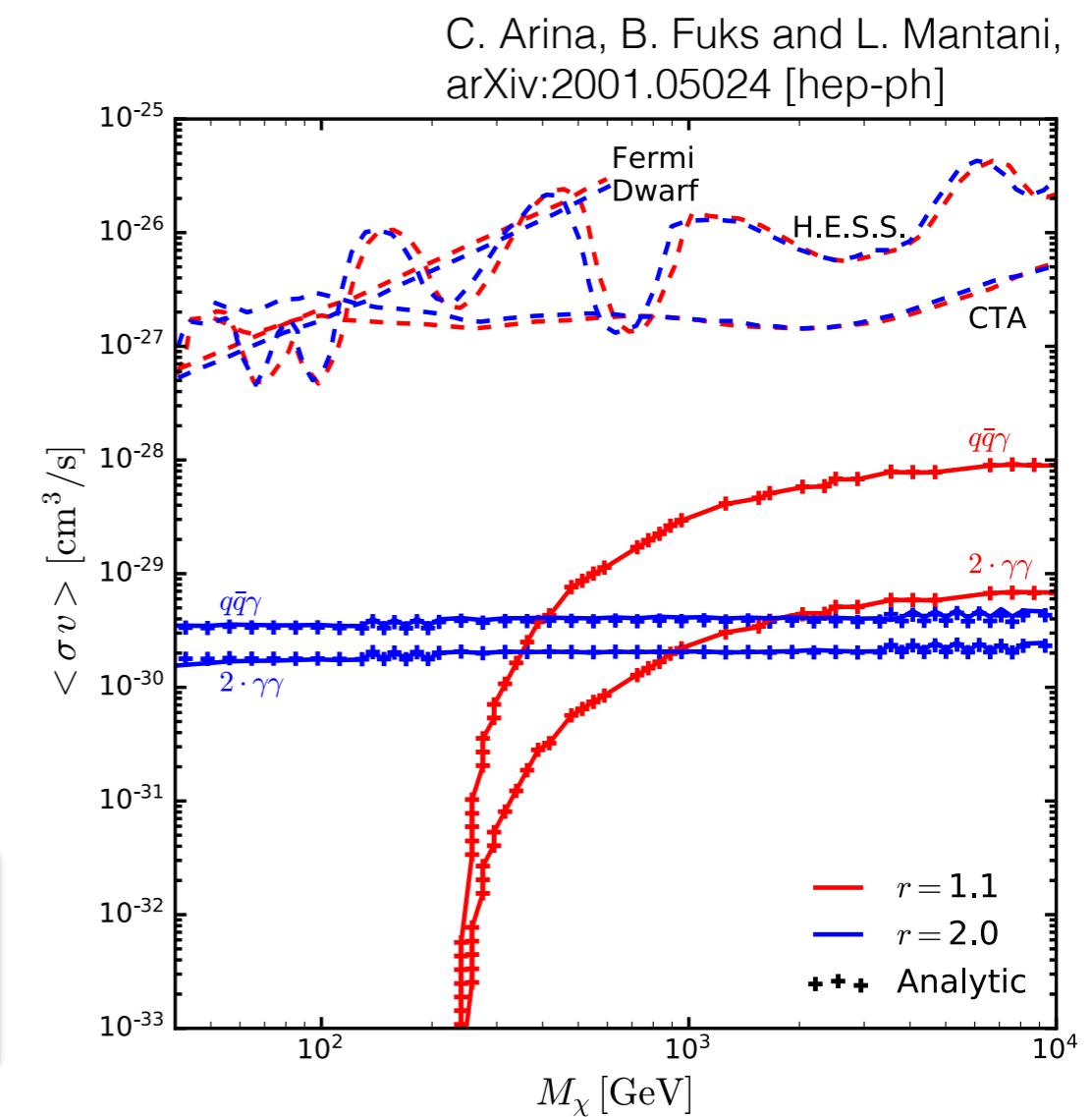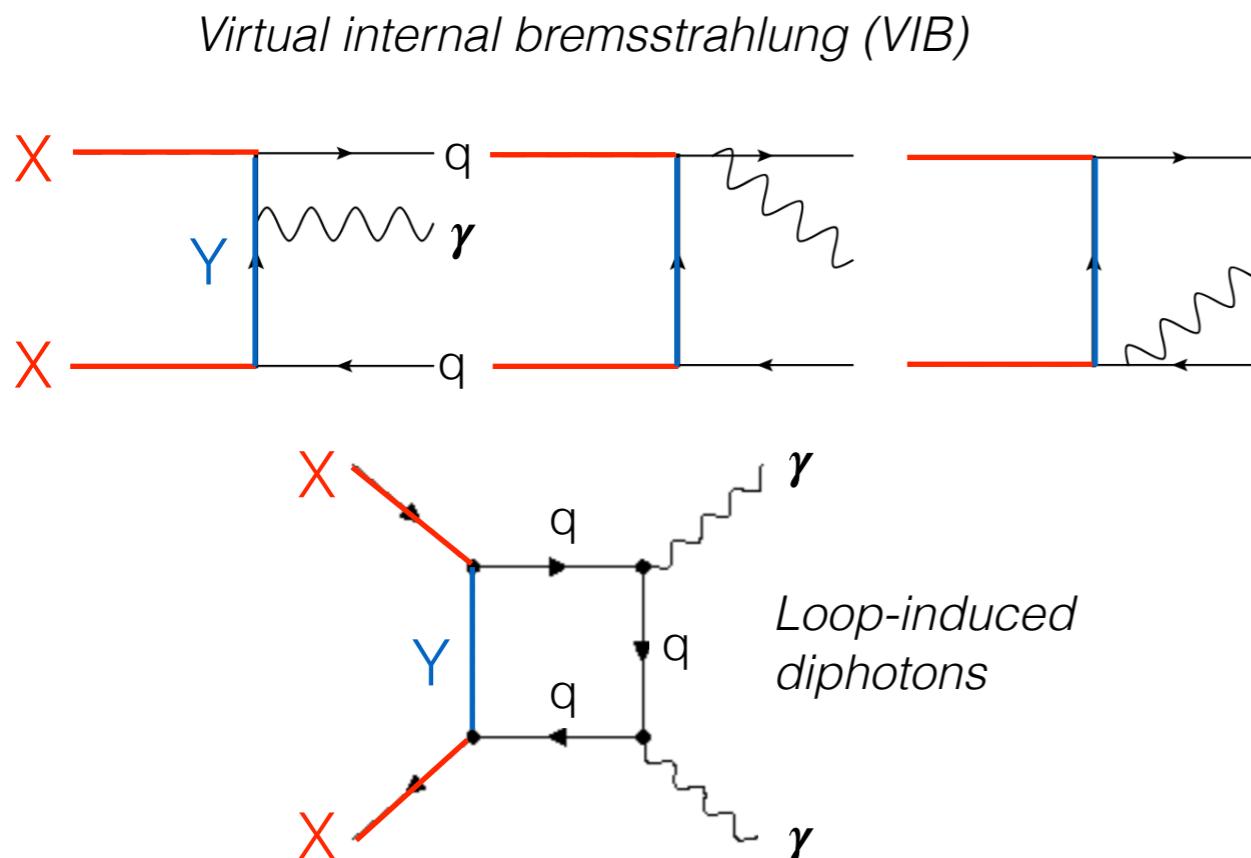
- Main references will be works by L. Lopez-Honorez and collaborators [Giacchino et al. (JCAP 2013)]
- Numerical computation with MadDM and NLO UFO files

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Example of benchmark model study*

Majorana DM coupling to up-right quark via scalar mediator (S3M_uR)

Viable parameter space compatible with relic density via freeze-out
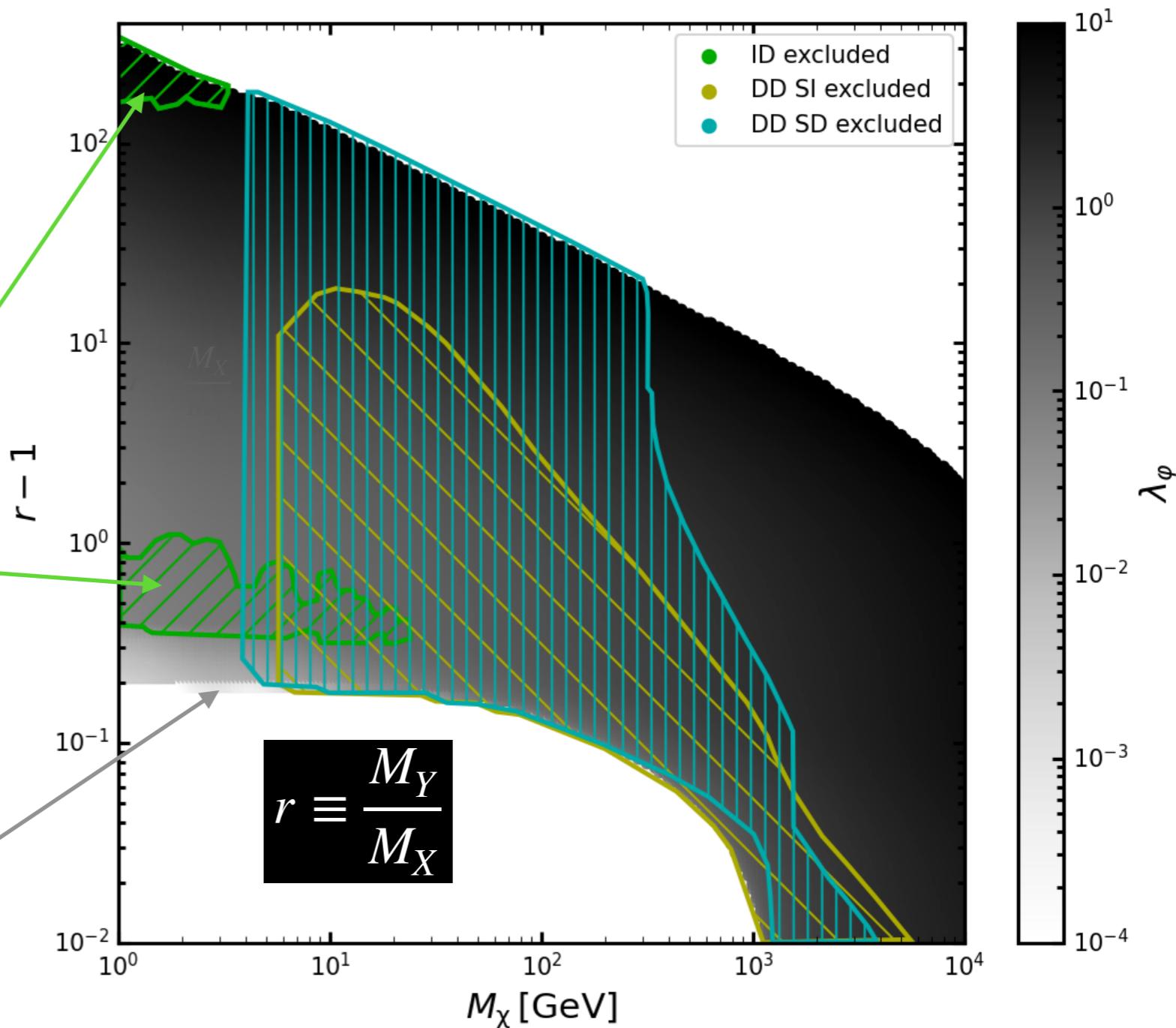
Gamma-ray bounds from lines and VIB

Region with small couplings gives rise to LLP

Region can be much bigger including freeze-in, not shown here

$$r \equiv \frac{M_Y}{M_X}$$

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Example of benchmark model study

Majorana DM coupling to up-right quark via scalar mediator (S3M_uR)

S3M u_R limits

□ LHC bound (CMS–SUS–19–006 recast)
300/fb projections: □ 2σ □ 5σ
3000/fb projections: □ 2σ □ 5σ
□ Cosmology bounds (combined)
□ Cosmology projections (combined)

$\Gamma_Y/M_Y = 5\%$

λ

Preliminary

M_X (GeV)

M_Y (GeV)

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Possible benchmark scenarios (I)

- Minimal framework of t-channel as in DMsimpt UFO package

- Universal scenario (coupling to all generations)

- Coupling to charm for charm tagging

- Connection with motivated theories

- Leptophilic models …

Name	DM	Mediators	Parameters
S3M_uni	$\tilde{\chi}$	$\varphi_{Q_f}, \varphi_{u_f}, \varphi_{d_f}$	
S3D_uni	χ		
S3M_3rd	$\tilde{\chi}$	$\varphi_{Q_3}, \varphi_{u_3}, \varphi_{d_3}$	$M_\varphi, M_\chi, \lambda_\varphi$
S3D_3rd	χ		
S3M_uR	$\tilde{\chi}$	φ_{u_1}	
S3D_uR	χ		
F3S_uni	$\tilde{S}$	$\psi_{Q_f}, \psi_{u_f}, \psi_{d_f}$	
F3C_uni	S		
F3S_3rd	$\tilde{S}$	$\psi_{Q_3}, \psi_{u_3}, \psi_{d_3}$	$M_S, M_\psi, \hat{\lambda}_\psi$
F3C_3rd	S		
F3S_uR	$\tilde{S}$	ψ_{u_1}	
F3C_uR	S		
F3V_uni	$\tilde{V}_\mu$	$\psi_{Q_f}, \psi_{u_f}, \psi_{d_f}$	
F3W_uni	V_μ		
F3V_3rd	$\tilde{V}_\mu$	$\psi_{Q_3}, \psi_{u_3}, \psi_{d_3}$	$M_V, M_\psi, \hat{\lambda}_\psi$
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coupling only to quark up-right

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S3D_3rd	χ		
S3M_uR	$\tilde{\chi}$	φ_{u_1}	
S3D_uR	χ		
F3S_uni	$\tilde{S}$	$\psi_{Q_f}, \psi_{u_f}, \psi_{d_f}$	
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F3C_uR	S		
F3V_uni	$\tilde{V}_\mu$	$\psi_{Q_f}, \psi_{u_f}, \psi_{d_f}$	
F3W_uni	V_μ		
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F3W_3rd	V_μ		
F3V_uR	$\tilde{V}_\mu$	ψ_{u_1}	
F3W_uR	V_μ		

coupling to all quarks

coupling only to quark up-right

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Possible benchmark scenarios (II)

- DMsimpt UFO package —> considers models in which the DM is an SU(2)xU(1) singlet and the mediator carries color or lepton number

- There exists other interesting possibilities that provide t-channel DM models:

  - DM is a doublet of SU(2), this gives rise to models of WINO or HIGGSINO dark matter

  - Pheno is very much different than DMsimpt models

  - Mediator is a charging-like particle

  - Models resemble scenarios of simplified SUSY models

- Leptophilic dark matter needs also to be defined, there exist also there multiple scenarios

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Conclusions

- Things are proceeding, the draft is being filled

- Description of the production of DM in the early universe needs polishing but main infos are there

- Now work will concentrate in the description of feature of minimal models for DM searches

- Direct and indirect searches have large dependence on the model

- Aim is to provide useful model parameter space for experimentalists to select viable benchmark points for searches

- Aims is also to highlight the connection of different models with different topologies and searches at LHC

Next cosmo meeting on June 27th @ 15.00 CEST

If you are interested in joining the cosmo group please contact me (Chiara.arina@uclouvain.be)

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