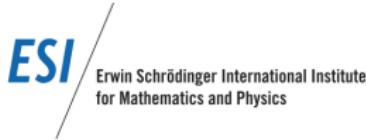


# Dark matter direct detection is testing Freeze-in

Laurent Vanderheyden  
Université Libre de Bruxelles

Based on  
*Phys. Rev. D98 (2018) 075017*  
T. Hambye, M.H.G. Tytgat, J. Vandecasteele and LV



Erwin Schrödinger International Institute  
for Mathematics and Physics



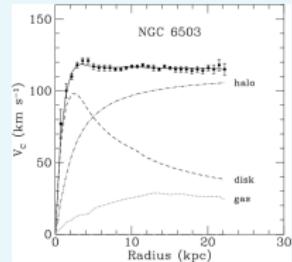
# Why do we study DM?

## Galaxies collisions :



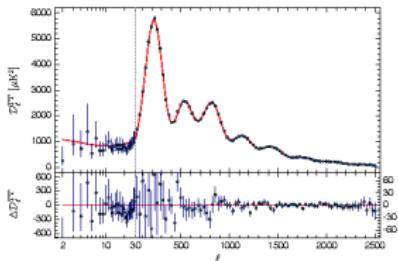
[M.Markevitch et al., 2006]

## Rotations curves :



[K.G. Begeman et al., 1991]

## CMB anisotropies :

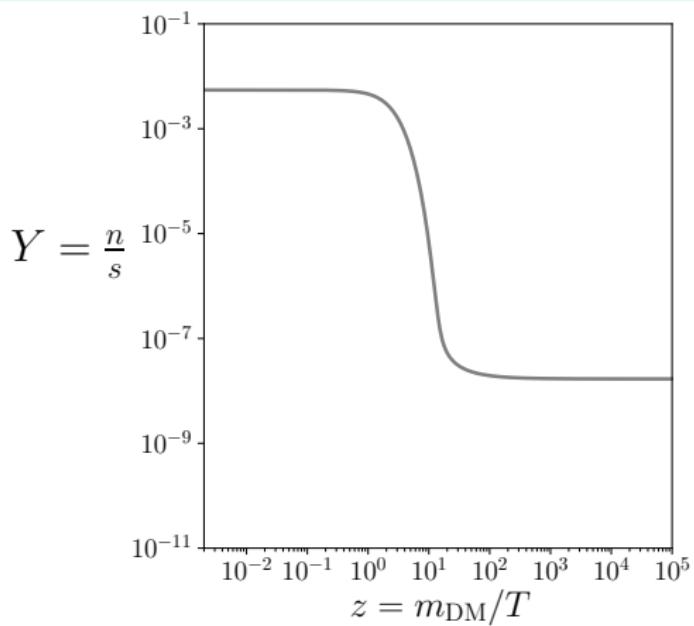


CMB anisotropies show  
that  $\Omega_{DM} h^2 \simeq 0.1188\%$

[Planck Collaboration, 2015]

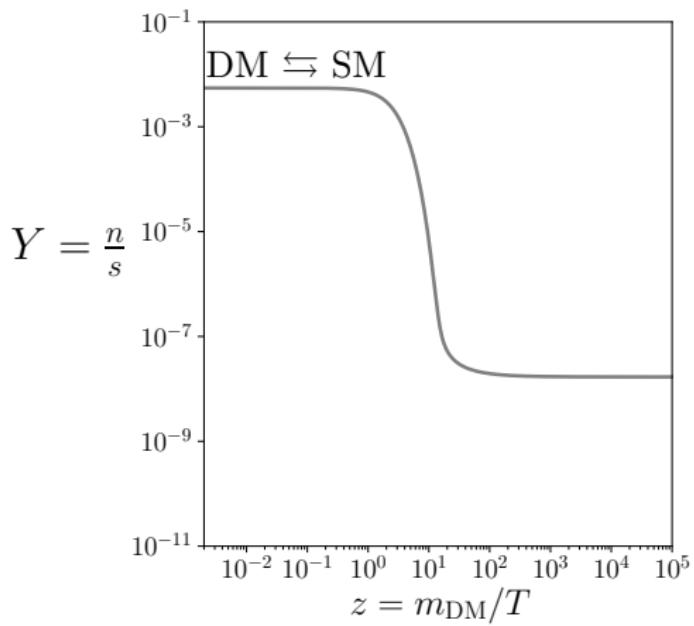
# How to produce the good relic abundance of DM?

## The standard Freeze-Out mechanism



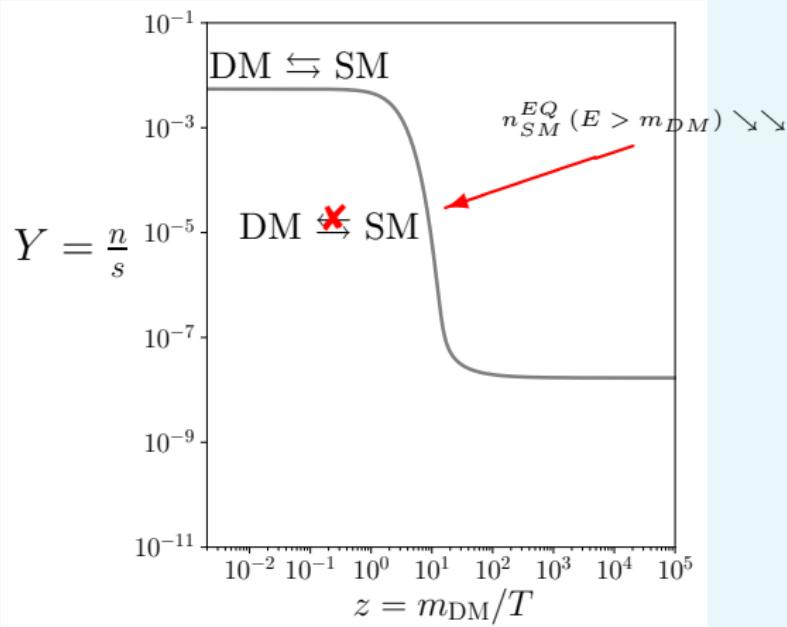
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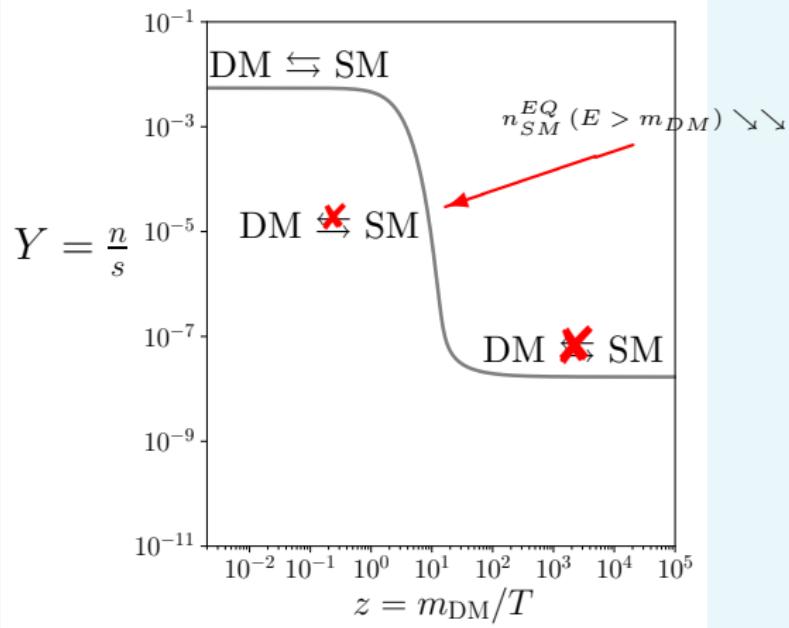
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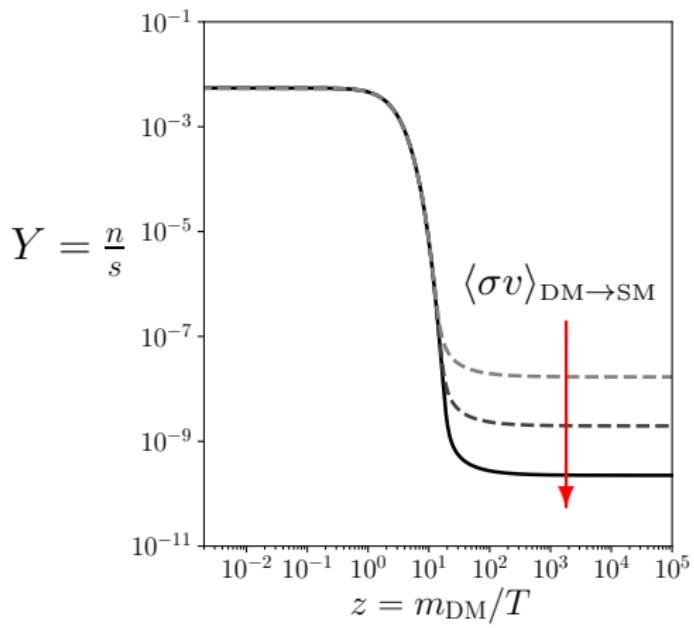
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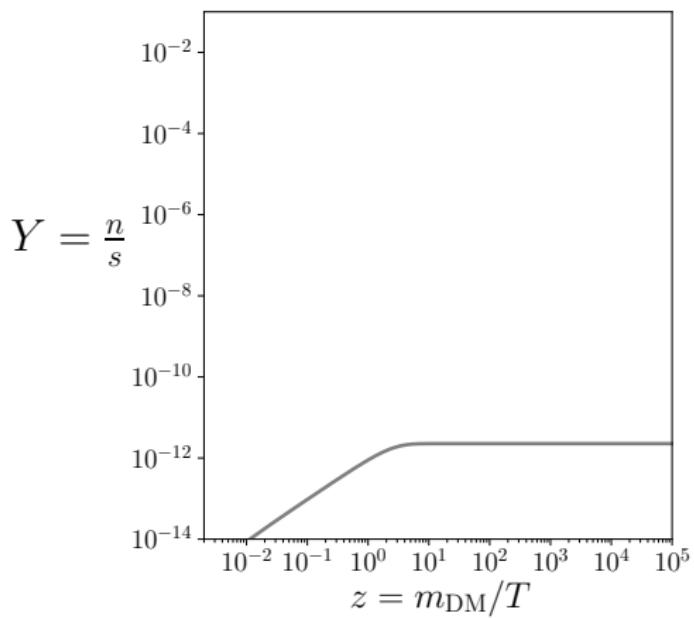
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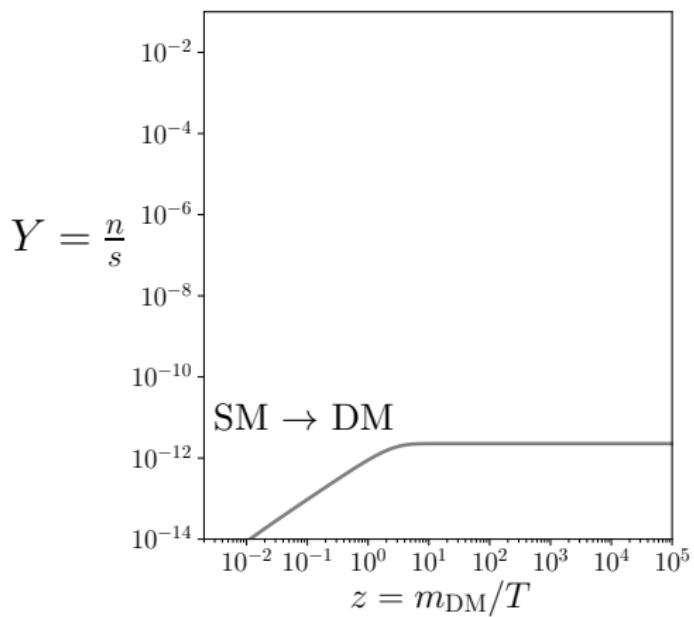
# Freezing-in the Dark Matter

## The Freeze-In mechanism



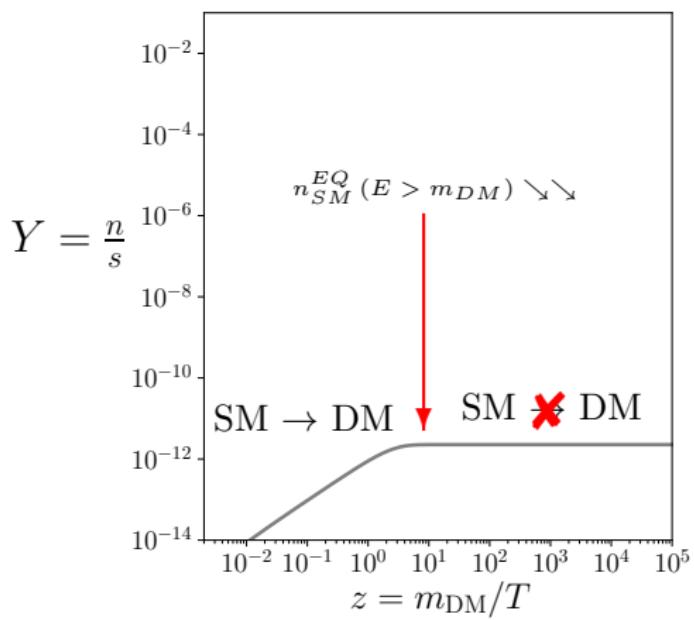
# Freezing-in the Dark Matter

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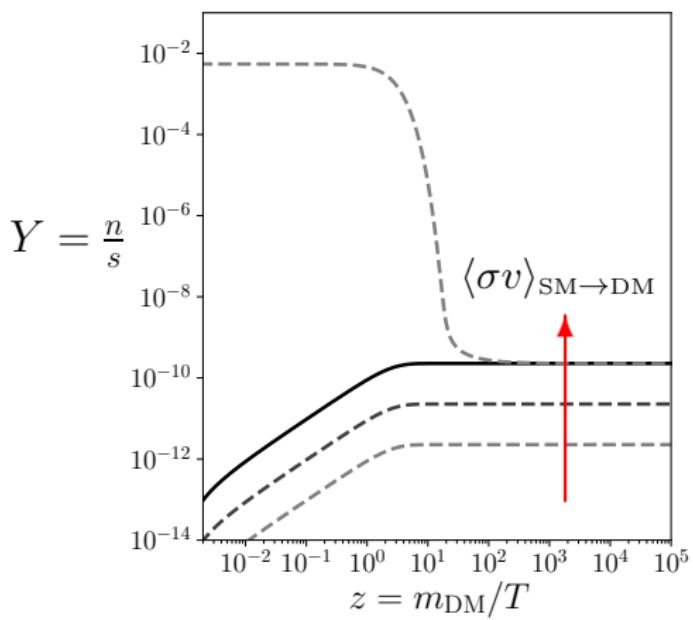
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# A simple model : millicharged DM

## The kinetic mixing portal model

$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} + \bar{\chi} (i\cancel{d} - m_\chi) \chi - \frac{\epsilon}{2} F_Y^{\mu\nu} F'_{\mu\nu}$$

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New  $U(1)'$  gauge symmetry : dark photon  $\gamma'$

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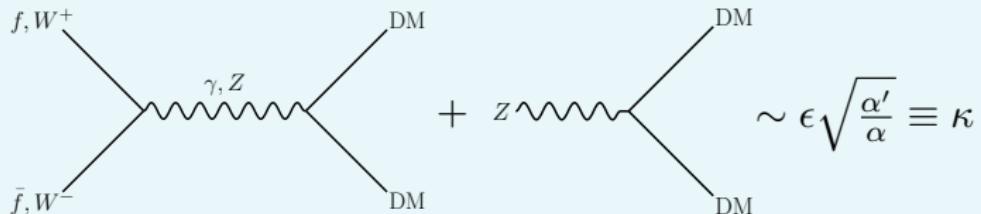
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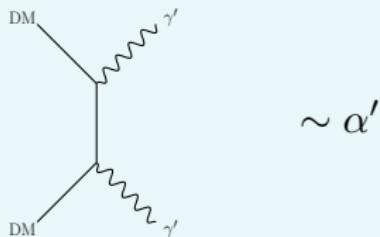
$U(1)' - U(1)_Y$  kinetic mixing term

# A simple model : millicharged DM

## DM productions channels

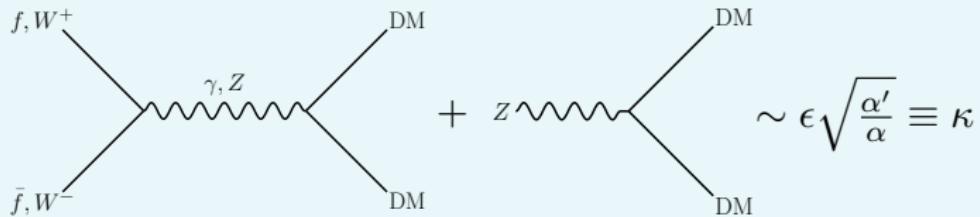


## DM annihilation channel

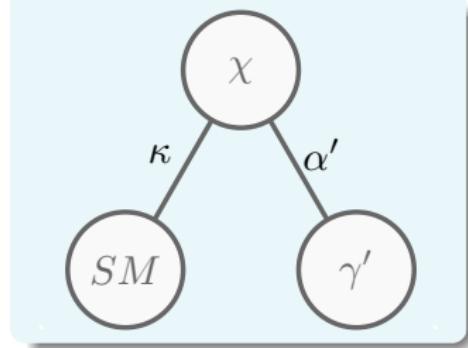
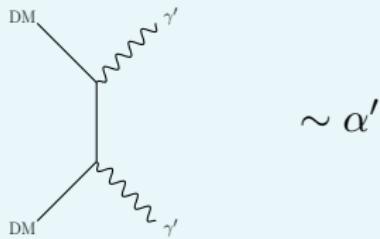


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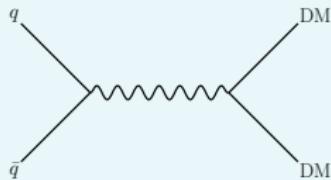


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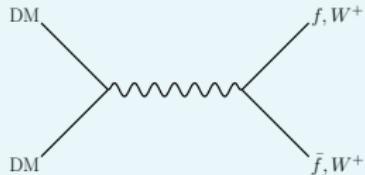
# How to constraint this model ?

## Collider



$$|\mathcal{M}|^2 \sim \alpha^2 Q_q^2 \kappa^2 \Rightarrow \text{Too small!}$$

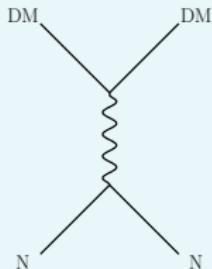
## Indirect detection



$$|\mathcal{M}|^2 \sim \alpha^2 Q_q^2 \kappa^2 \Rightarrow \text{Too small!}$$

# How to constraint this model ?

## Direct detection with a light mediator



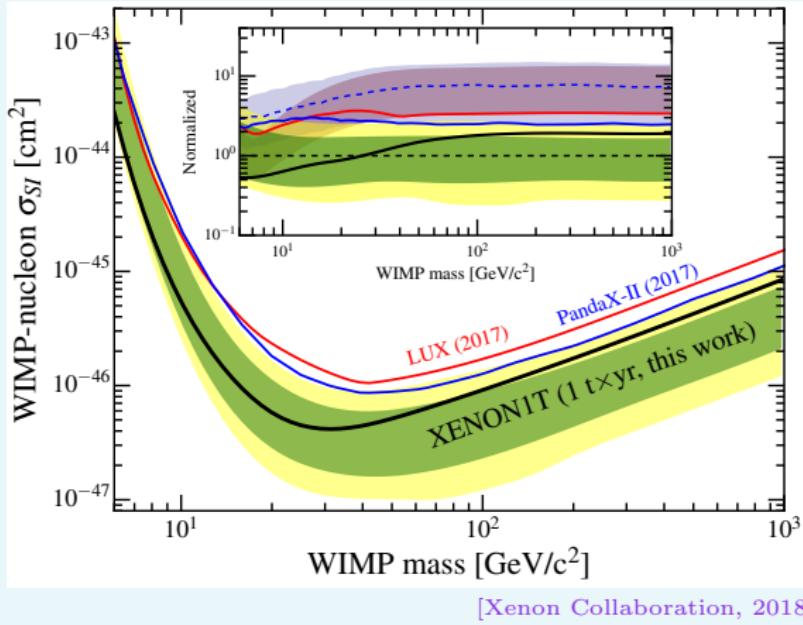
$$\sim \frac{1}{t - m_{\gamma'}^2} \sim \frac{1}{t} \sim \frac{1}{2m_N E_R}$$

$$\Rightarrow |\mathcal{M}|^2 \sim \frac{1}{E_R^2} \alpha^2 Q_q^2 \kappa^2$$

Direct detection signal is boosted by  $1/E_R^2$ .  
This boost can compete very small couplings  
at low recoil energy !

# Direct detection limits

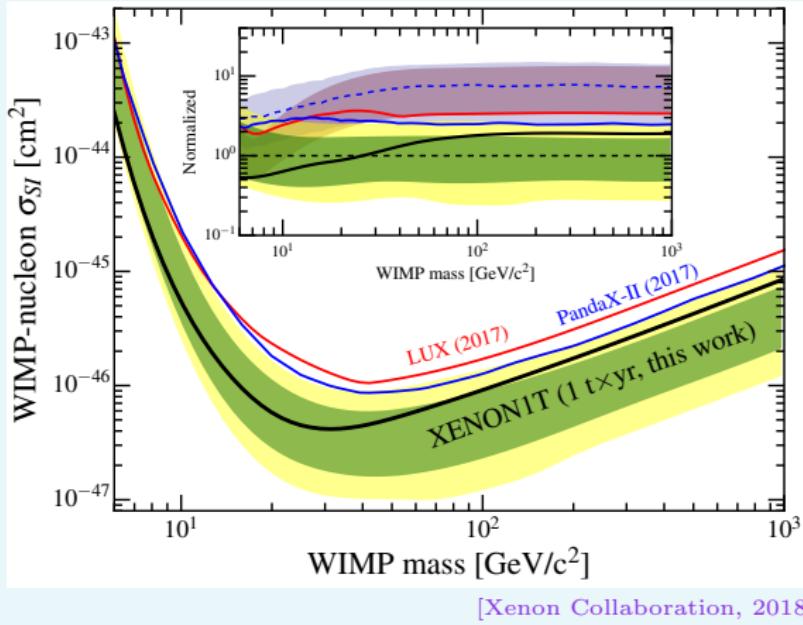
Constraints on the WIMP-nucleon elastic cross section - current status :



Valid only for a constant cross section !

# Direct detection limits

Constraints on the WIMP-nucleon elastic cross section - current status :



Valid only for a constant cross section !

We need to recast the limits for a FIMP-nucleon elastic cross section !

## Measurable recoil energy differential rate

$$\frac{dR}{dE_R} = \left[ \frac{1}{2} \epsilon(E_R) N_T m_N F^2(qr_A) \right] \left[ \frac{1}{\mu_{\chi p}^2} \sigma_{\chi p}(E_R) Z^2 \right] \left[ n_\chi \int \frac{1}{v^2} f_E(\vec{v}) d^3v \right]$$

# Recast

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### Detector physics

$\epsilon$  : Detector

efficiency

$N_T$  : Number of  
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$m_N$  : Nucleus mass

$F$  : Form factor

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$\mu_{\chi p}$  : Reduced mass

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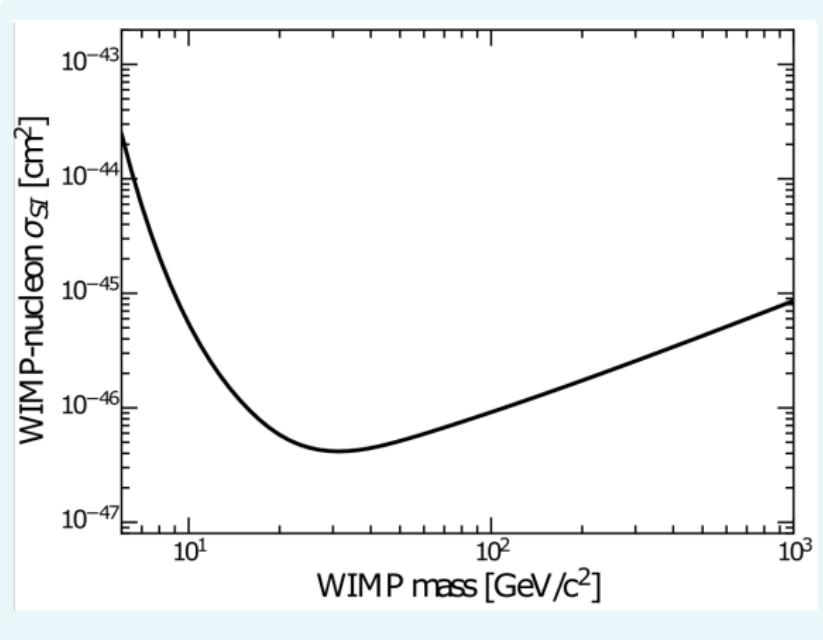
### Astrophysics

$n_\chi$  : Local DM number density

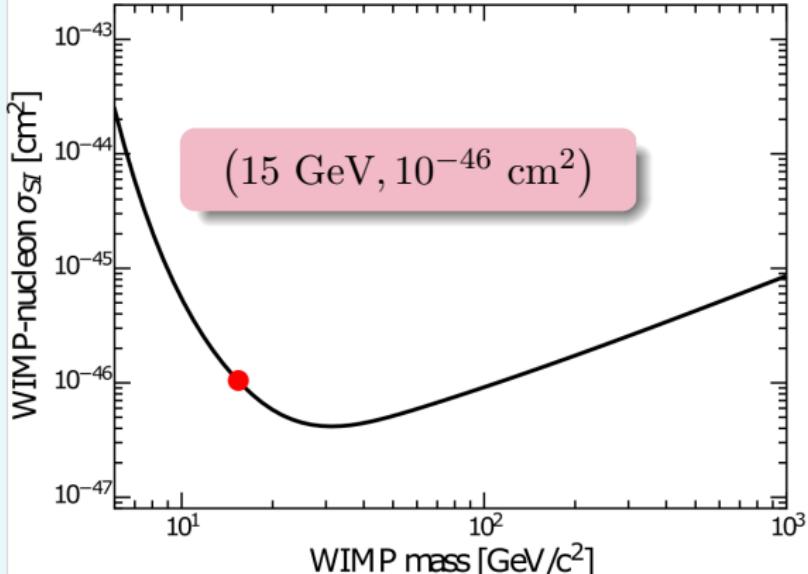
$v$  : DM velocity

$f_E$  : DM velocity distribution in the Earth frame

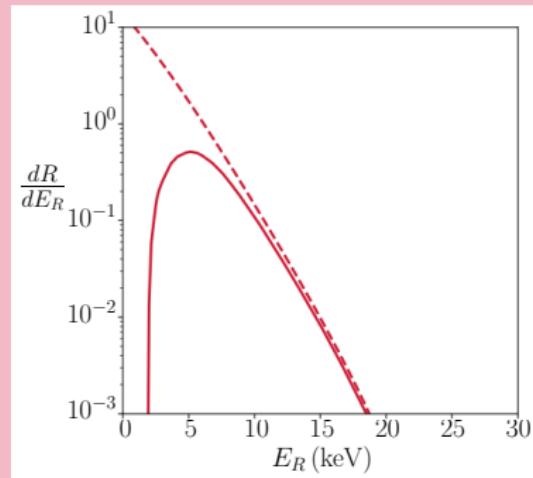
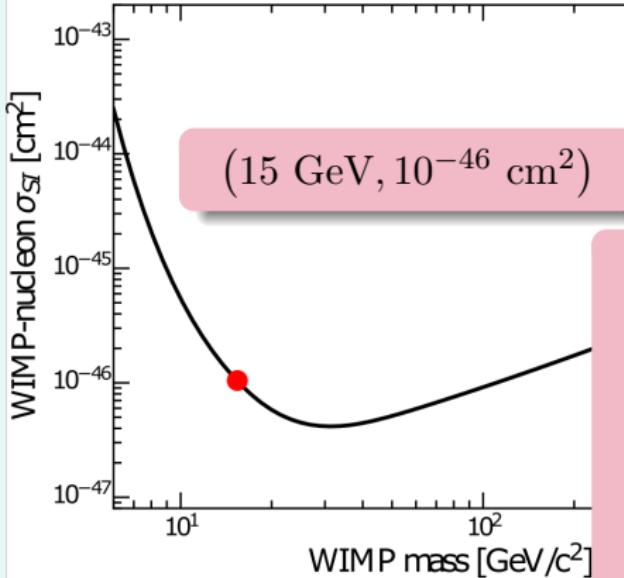
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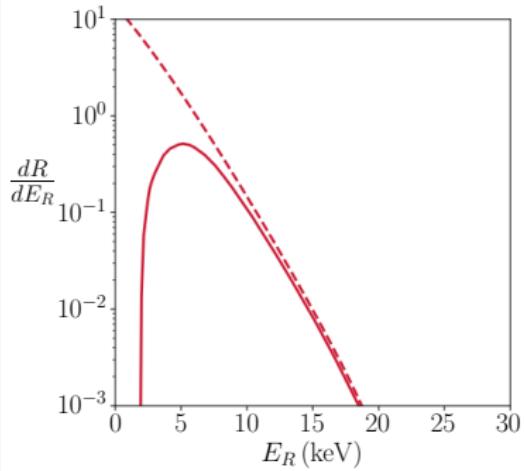


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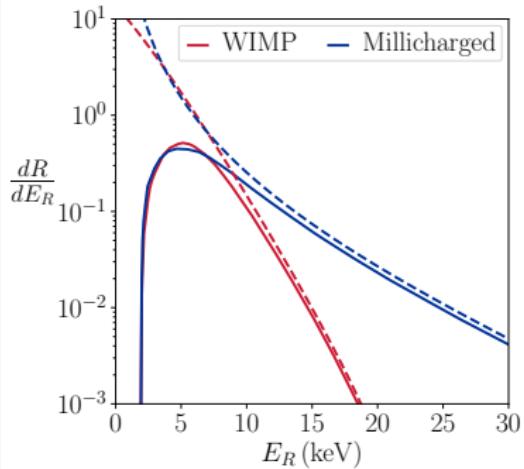
## Matching the rates



WIMP :  
 $(m_\chi, \sigma_{SI}) = (15 \text{ GeV}, 10^{-46} \text{ cm}^2)$

# Recast

## Matching the rates



$$\text{WIMP :} \\ (m_\chi, \sigma_{SI}) = (15 \text{ GeV}, 10^{-46} \text{ cm}^2)$$

$$\text{Millicharged :} \\ (m_\chi, \kappa) = (68 \text{ GeV}, 3 \times 10^{-11}) \\ \Delta \simeq 0.23$$

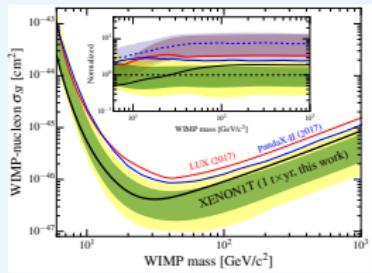
[T. Hambye, M.H.G. Tytgat, J. Vandecasteele and LV, 2018]

$$\Delta^2 \equiv \frac{1}{R^2} \int \left( \frac{dR}{dE_R} - \frac{dR'}{dE_R} \right)^2 dE_R < (0.3)^2$$

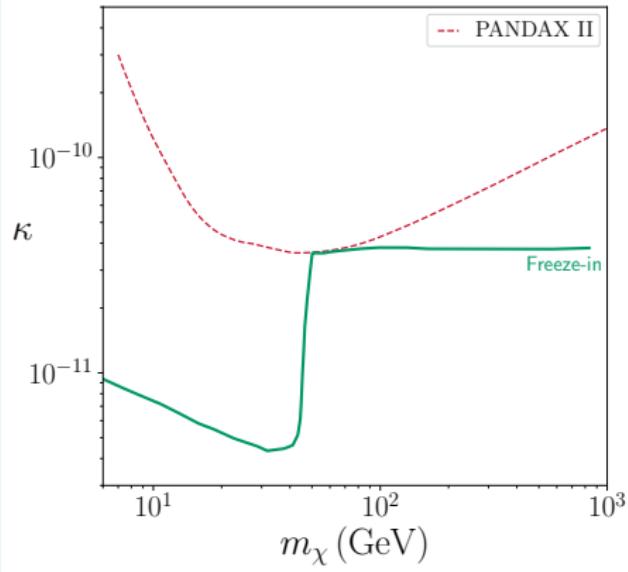
# Results

## Constraints on Millicharged DM

### Constraints on WIMP



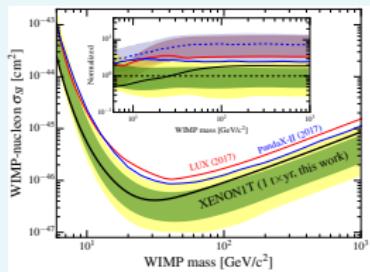
[Xenon Collaboration, 2018]



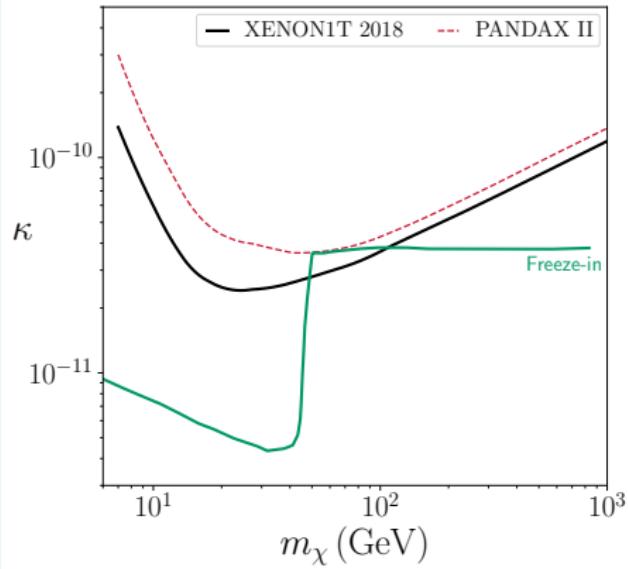
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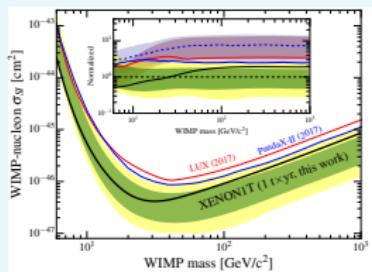
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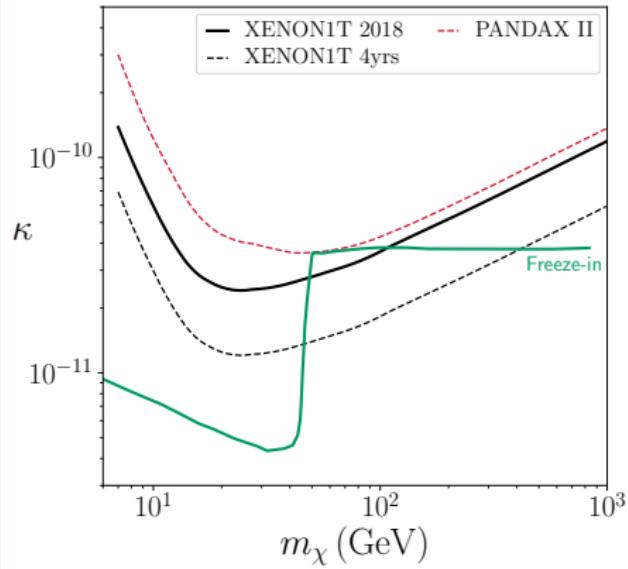
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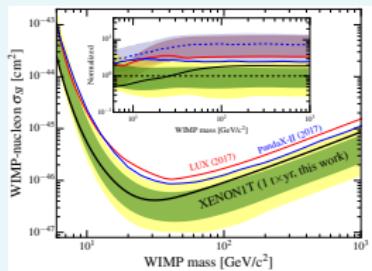
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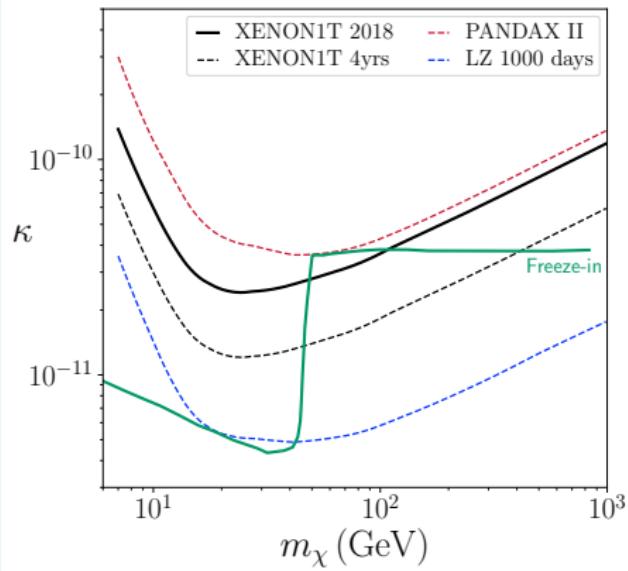
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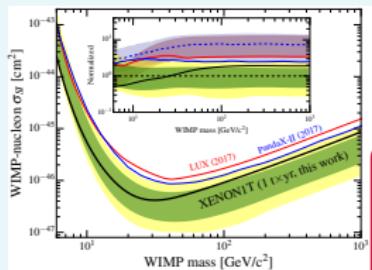


[T. Hambye, M.H.G. Tytgat, J. Vandecasteele and LV, 2018]

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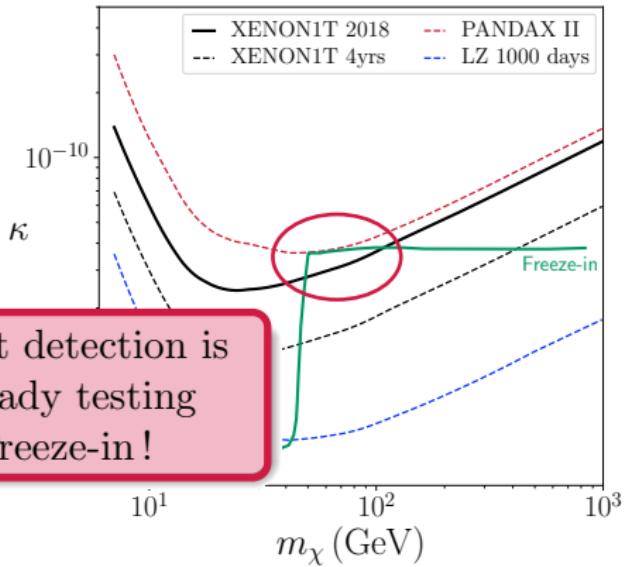
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[Xenon Collaboration, 2018]

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[T. Hambye, M.H.G. Tytgat, J. Vandecasteele and LV, 2018]

# Conclusion

Based on :

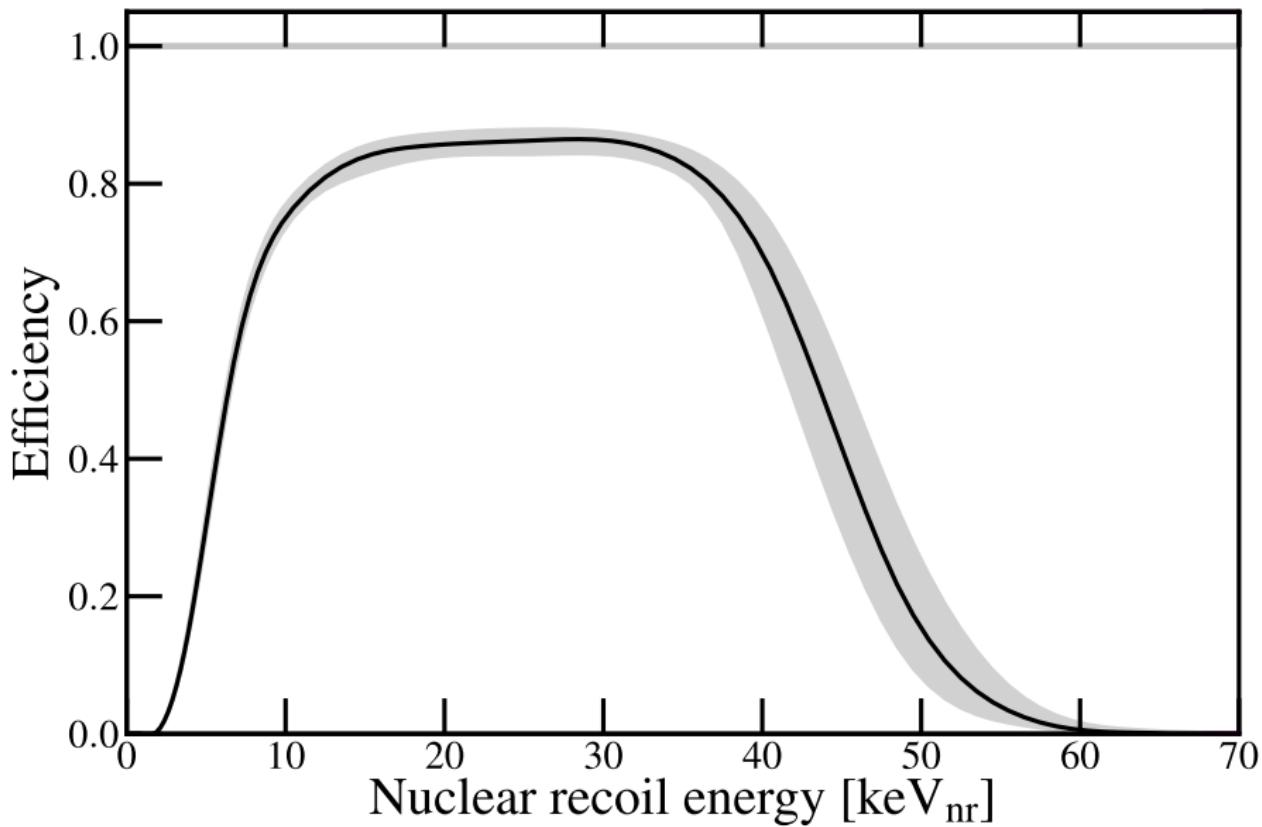
- Freeze-in mechanism for DM production in the Early Universe,
- Direct detection of DM from the galactic halo.

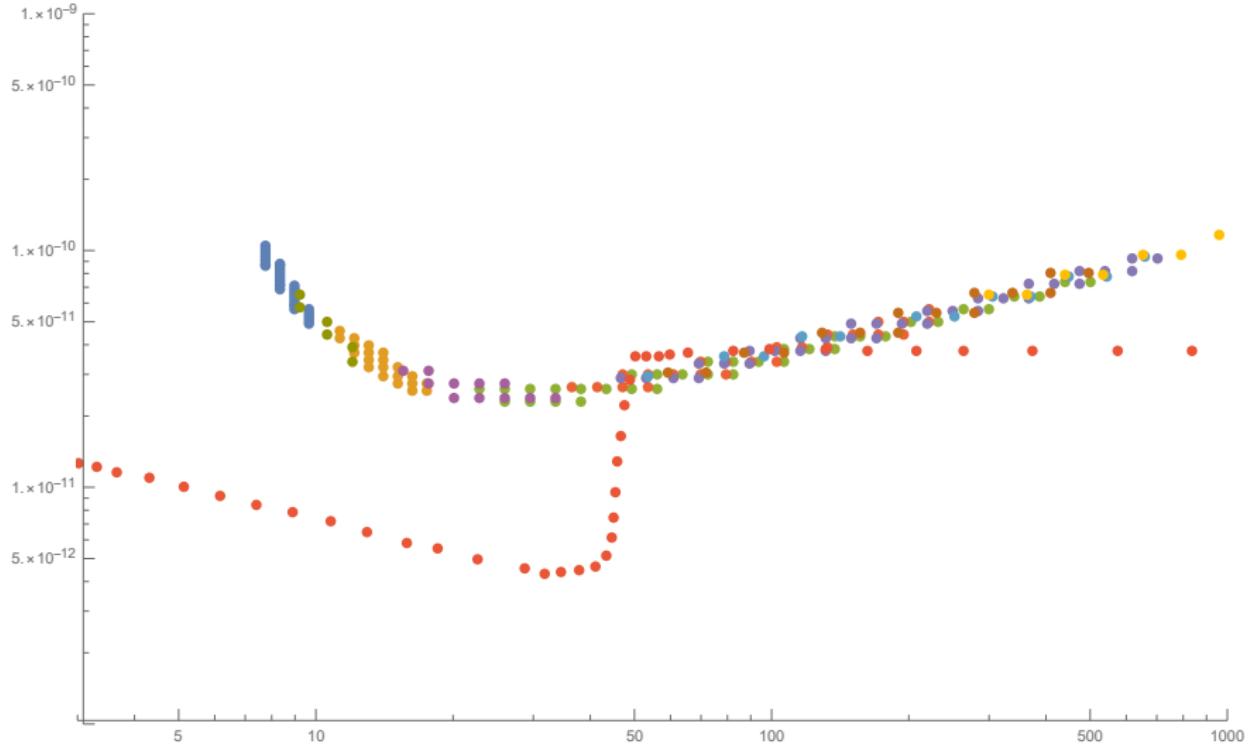
Considering a millicharged DM model, we have shown that :

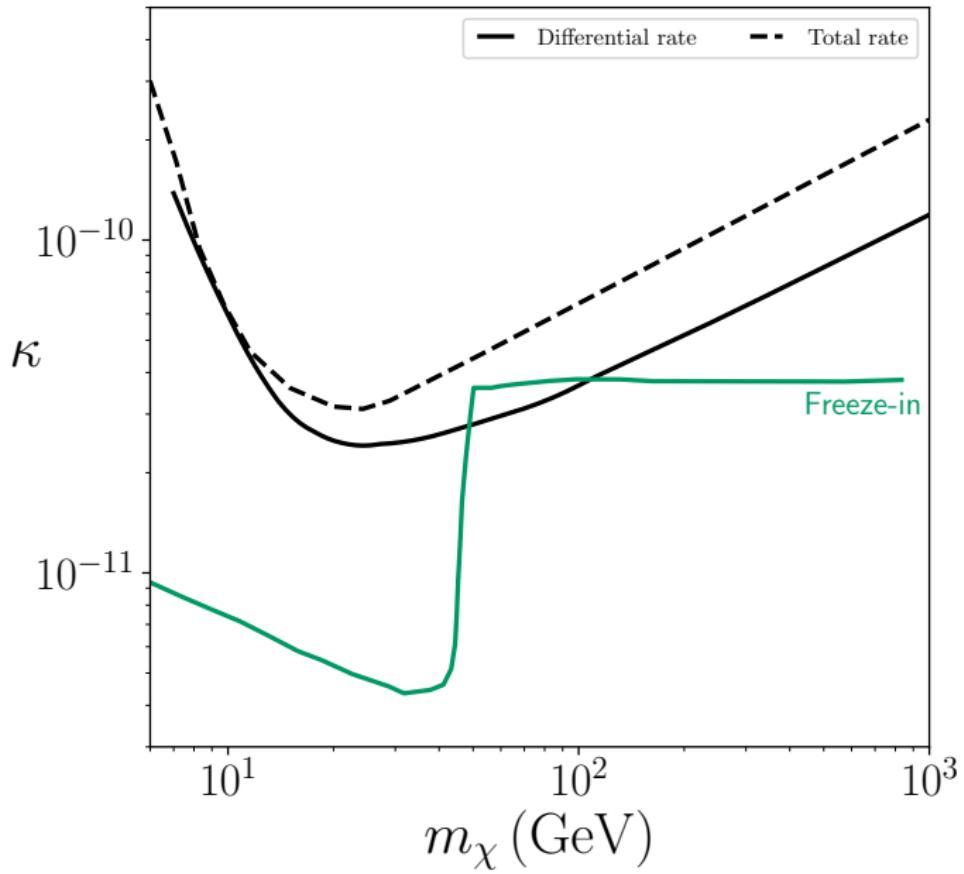
- ⇒ Following Xenon1T 2018 data, Freeze-in DM candidate are being constrained at the GeV scale for the first time.

Thank you for your attention !

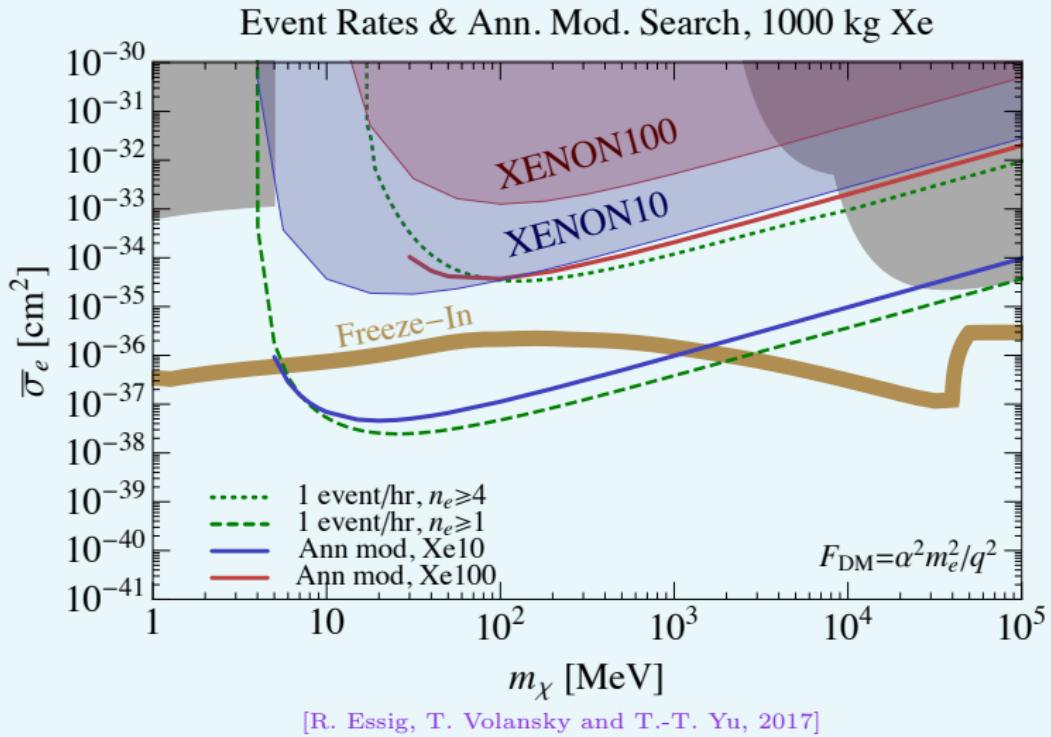
# Backup slides







# DM-electron scattering



# What if the dark photon has a mass ?

The kinetic mixing portal model : massive case

$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} + \bar{\chi} (i\cancel{d} - m_\chi) \chi - \frac{\epsilon}{2} F_Y^{\mu\nu} F'_{\mu\nu} + \frac{1}{2} m_{\gamma'} A'^{\mu} A'_\mu$$

[Babu, Kolda and March-Russel, 1997]

$$\Rightarrow \mathcal{L}_I = -\frac{e}{s_w c_w} J_Z^\mu Z_\mu - e' J_\chi^\mu (\epsilon s_w Z_\mu - \gamma'_\mu) + e J_{EM}^\mu (\gamma_\mu - \epsilon c_w \gamma'_\mu)$$

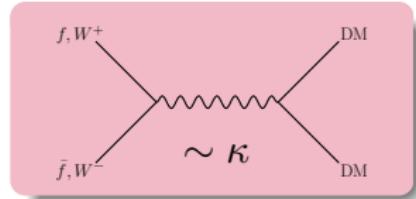
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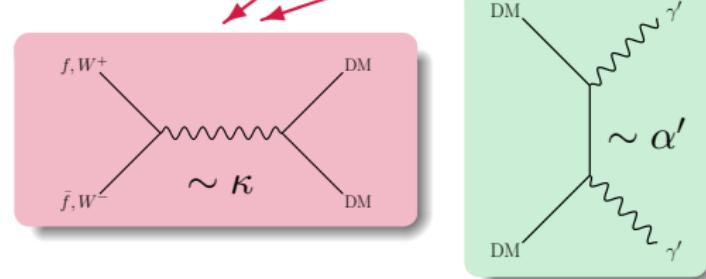
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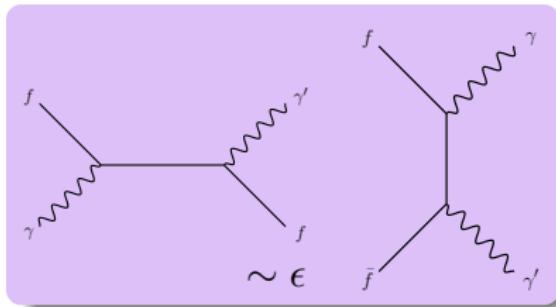
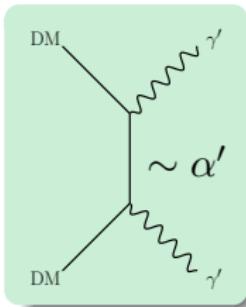
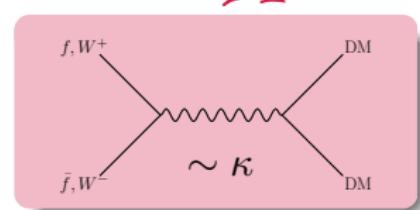
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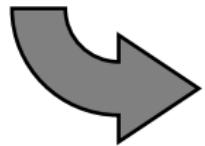
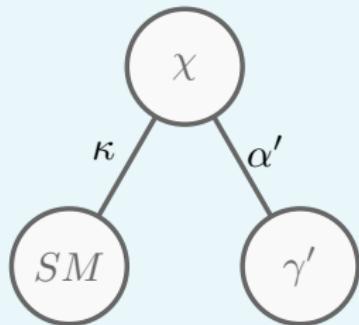
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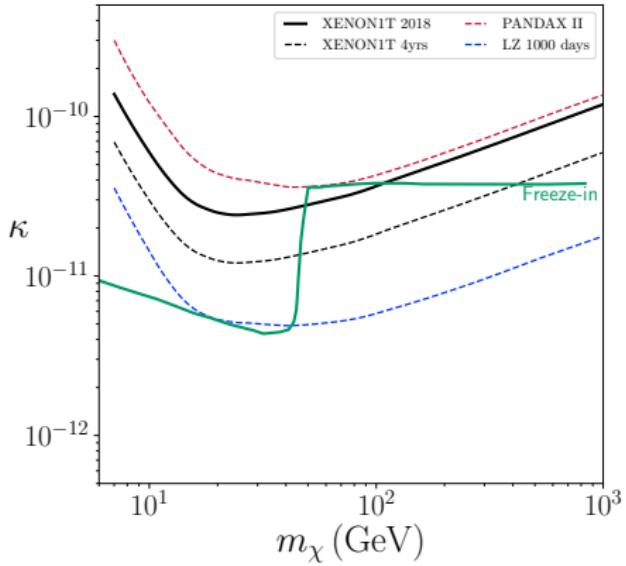


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New phenomenology !



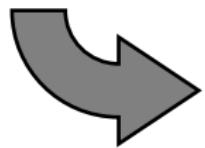
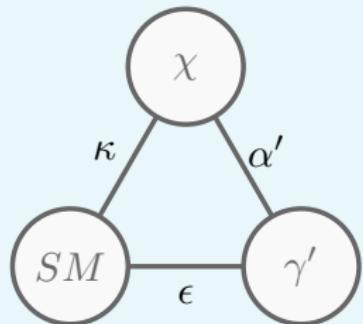
Feebler couplings !



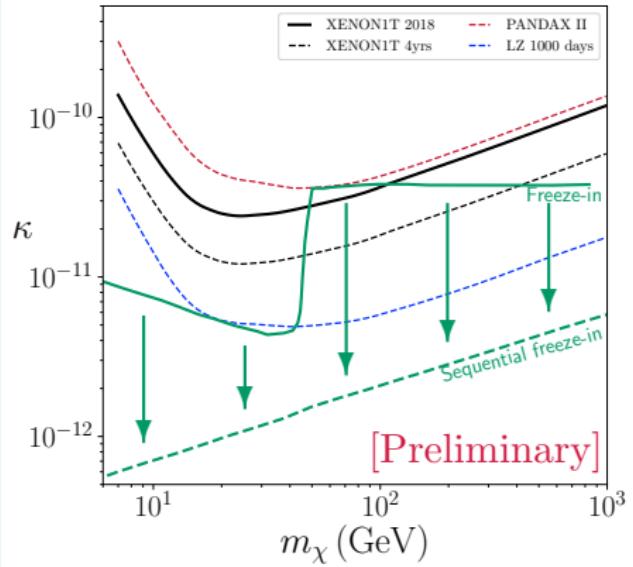
[T. Hambye, M.H.G. Tytgat, J. Vandecasteele and LV, 2018]

# What if the dark photon has a mass ?

New phenomenology !



Feebler couplings !



[T. Hambye, M.H.G. Tytgat, J. Vandecasteele and LV, [2019](#)]

