

Status of fermionic sub-GeV Dark Matter

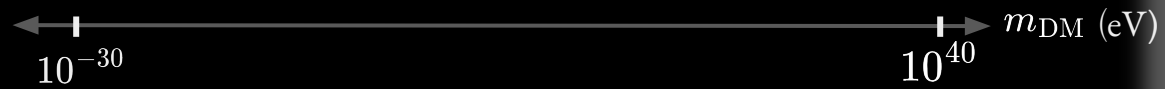
Sowmiya Balan

[arXiv:2405.17548](https://arxiv.org/abs/2405.17548)

In collaboration with: Csaba Balazs, Torsten Bringmann, Christopher Cappiello, Riccardo Catena, Timon Emken, Tomás E. Gonzalo, Taylor R. Gray, Will Handley, Quan Huynh, **Felix Kahlhoefer**, and Aaron C. Vincent

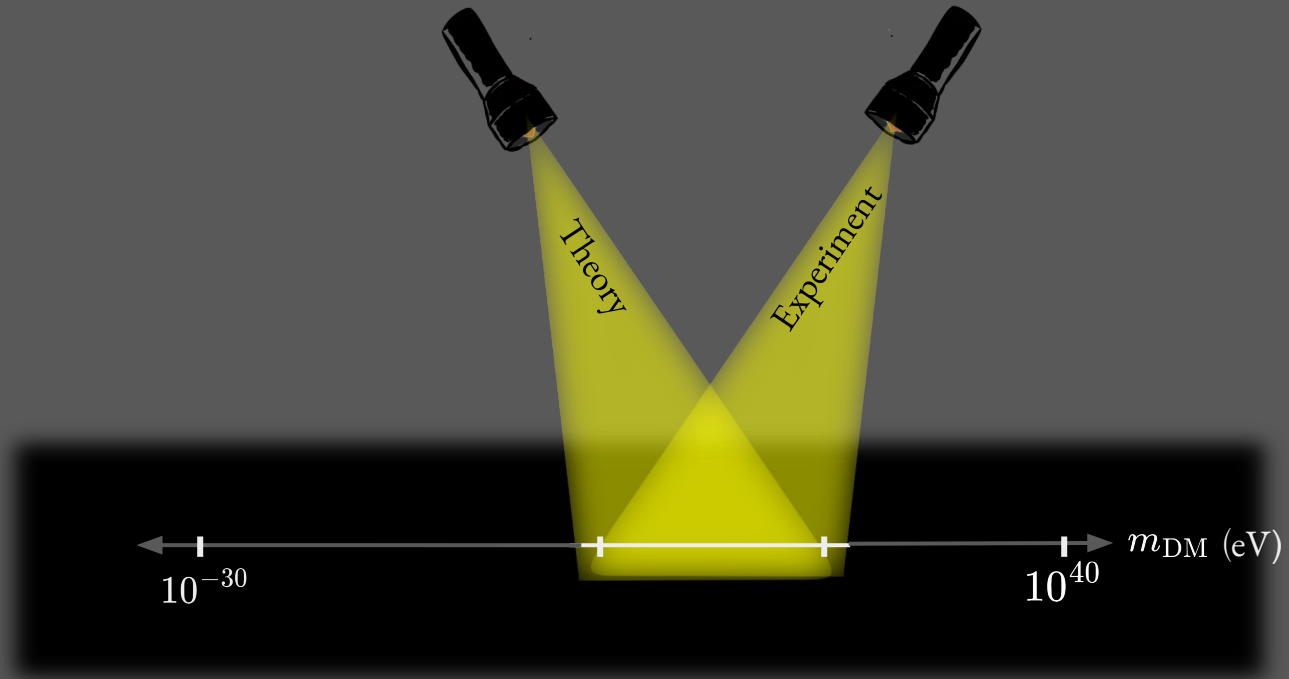
What is the mass of dark matter?





Status of sub-GeV Dark Matter

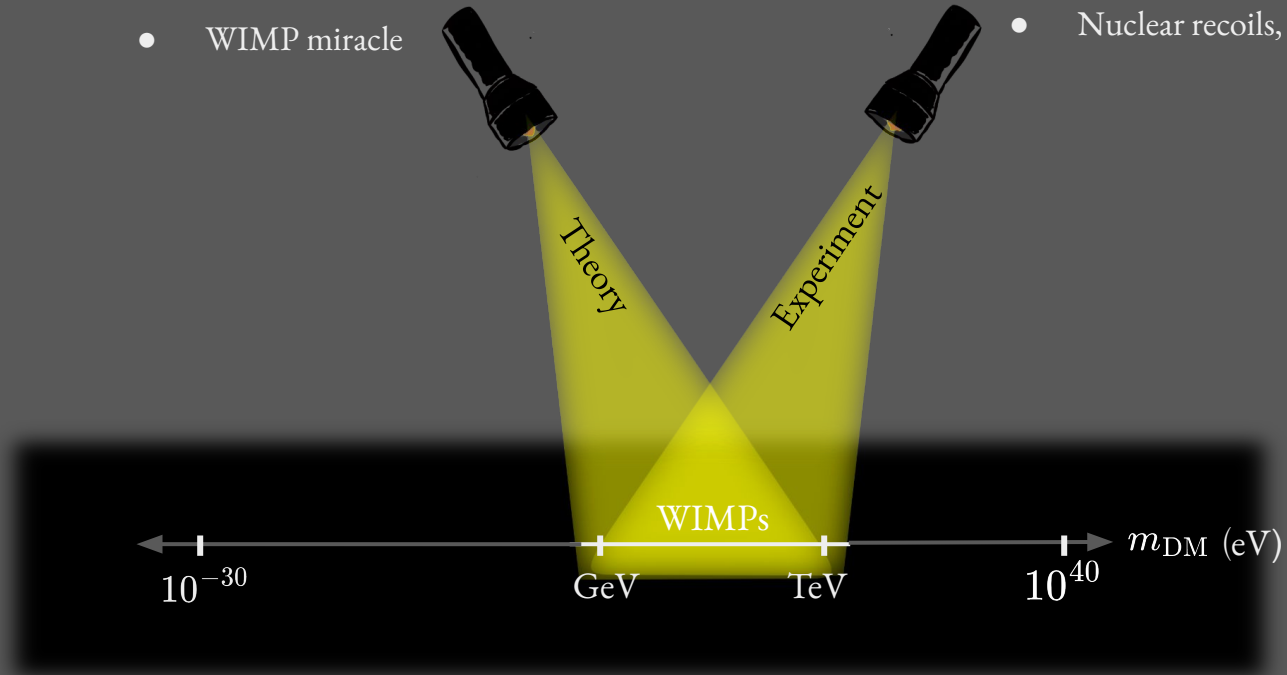
Motivation



Status of sub-GeV Dark Matter Motivation

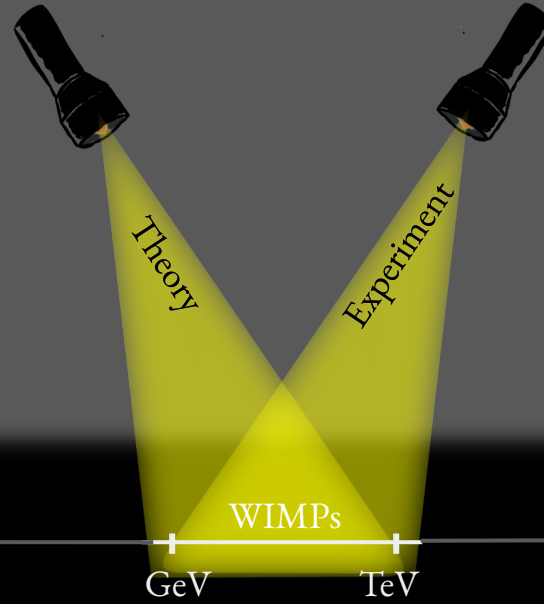
- WIMP miracle

- Nuclear recoils, annihilation products

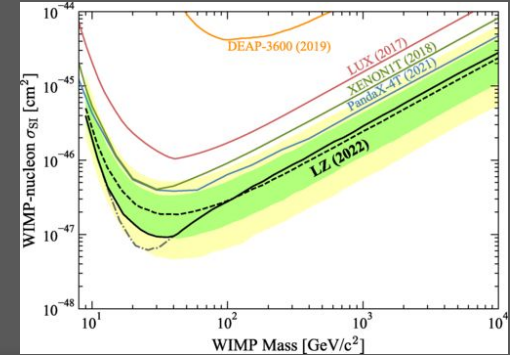


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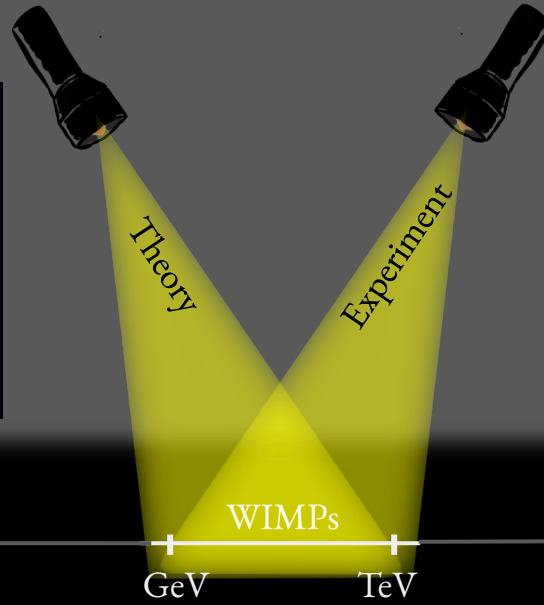
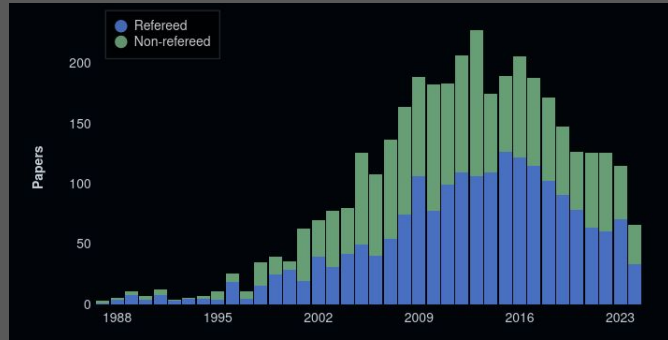


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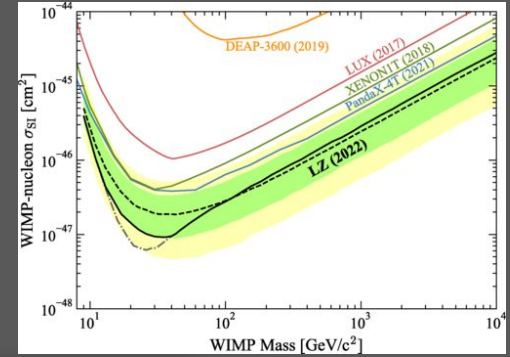


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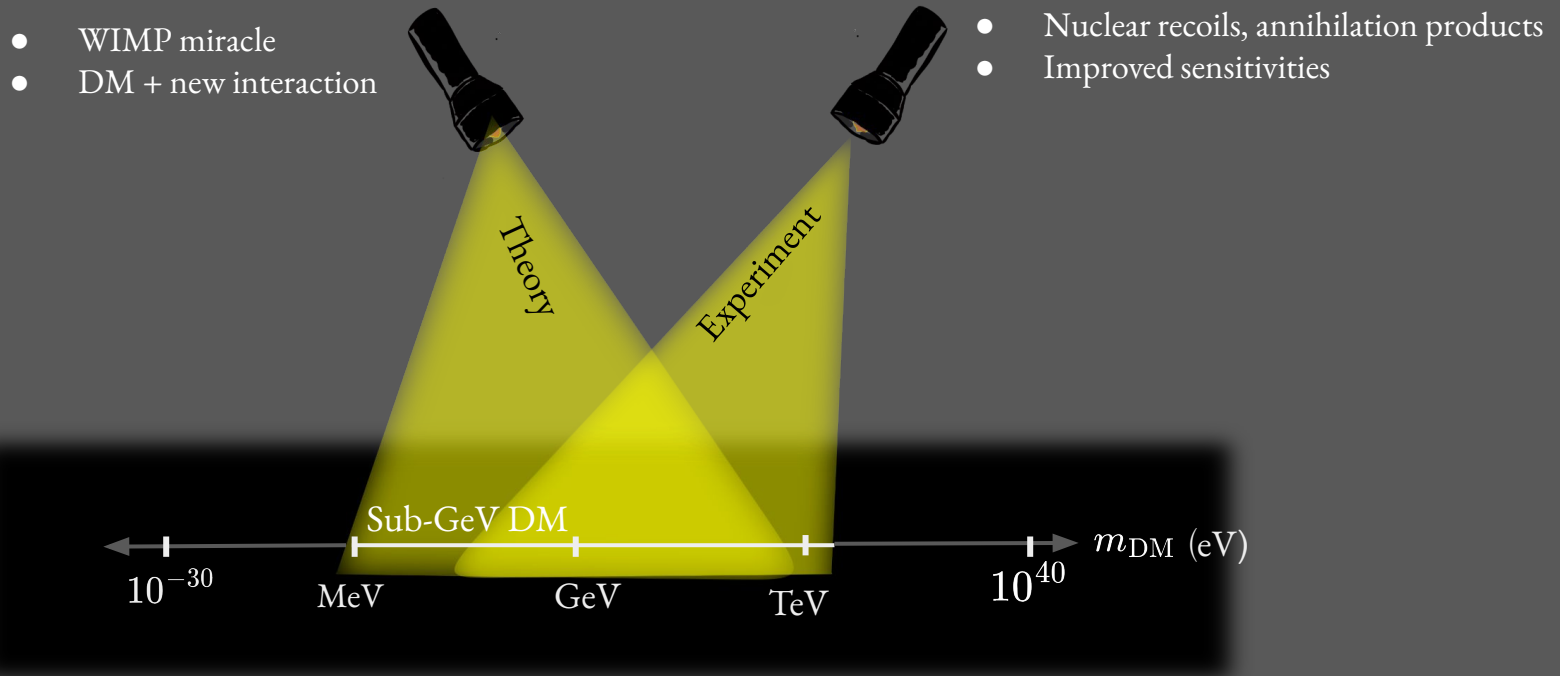


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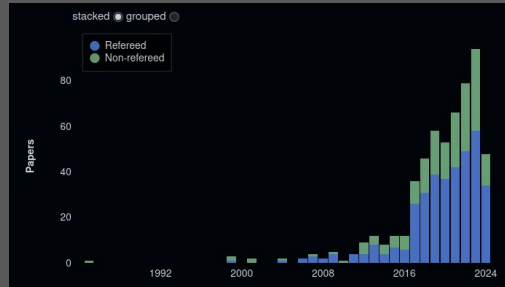
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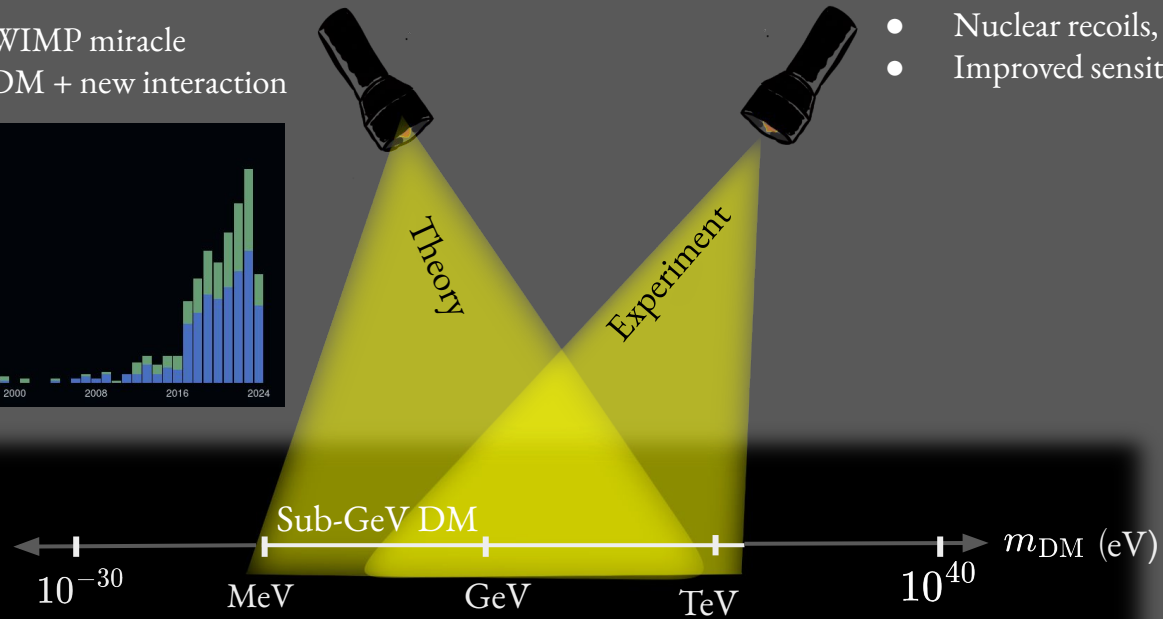
Status of sub-GeV Dark Matter

Motivation

- WIMP miracle
- DM + new interaction



- Nuclear recoils, annihilation products
- Improved sensitivities



- Dirac fermion stable due to $U(1)$ gauge symmetry

$$\mathcal{L}_\psi = \bar{\psi}(i\not{\partial} - m_{\text{DM}})\psi + g_{\text{DM}}A'^\mu\bar{\psi}\gamma_\mu\psi$$

- Portal to SM through dark photon A' with kinetic mixing

$$\mathcal{L}_{\text{int}} = -\frac{1}{2}m_{A'}^2A'^\mu A'_\mu - \frac{1}{4}A'^{\mu\nu}A'_{\mu\nu} - \kappa eA'^\mu \sum_f q_f \bar{f}\gamma_\mu f$$

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Parameter name	Symbol
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Dark sector coupling	g_{DM}
Dark photon mass	$m_{A'}$
Kinetic mixing	κ

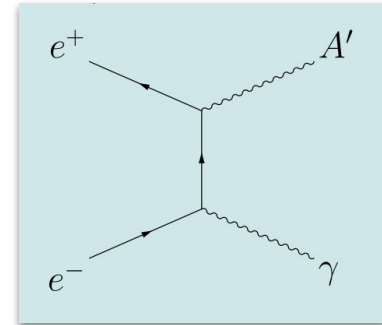
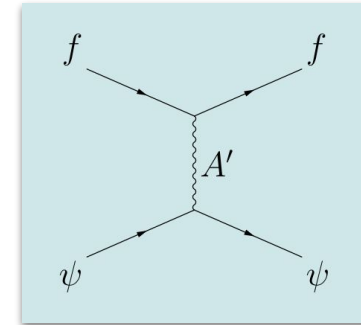
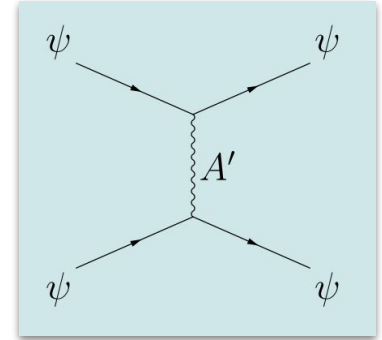
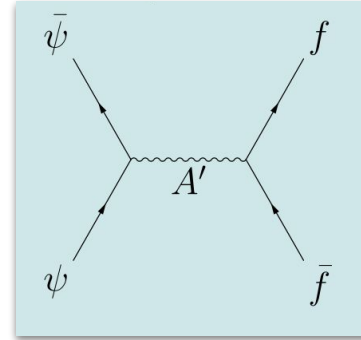
$$m_{\text{DM}} < m_{A'}/2$$

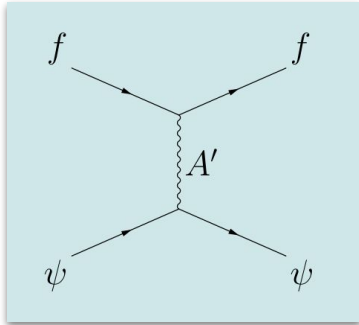
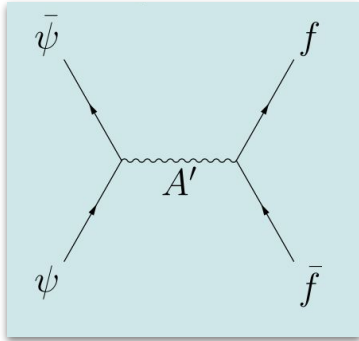
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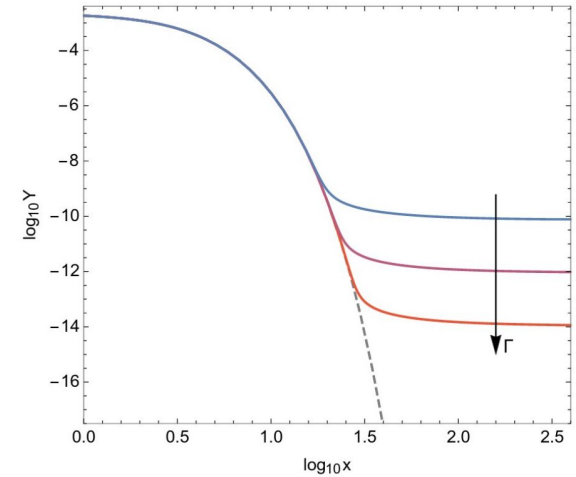
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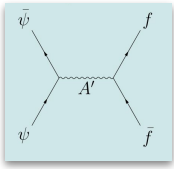
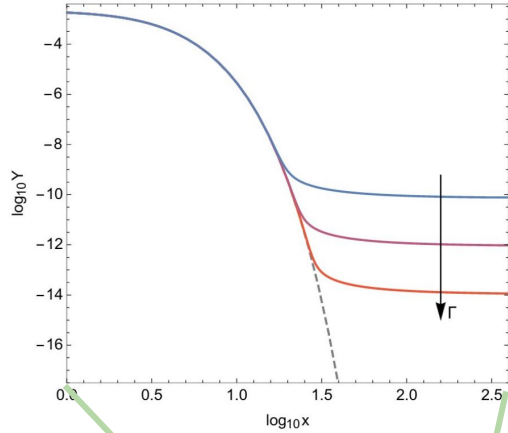


- $T \gg m_{\text{DM}}$: DM in kinetic and chemical equilibrium with SM
- $T < m_{\text{DM}}$: Boltzmann suppression
- $\Gamma_{\text{ann}} \ll H$: Chemical decoupling



Status of sub-GeV Dark Matter

Freeze-out

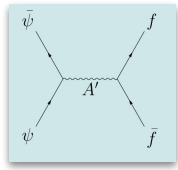
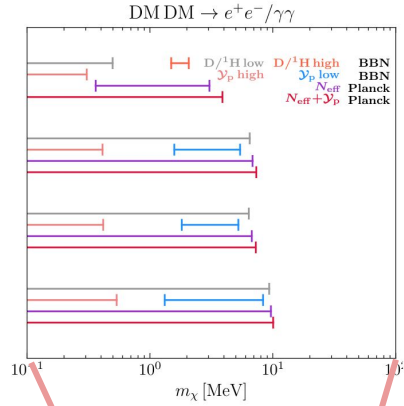
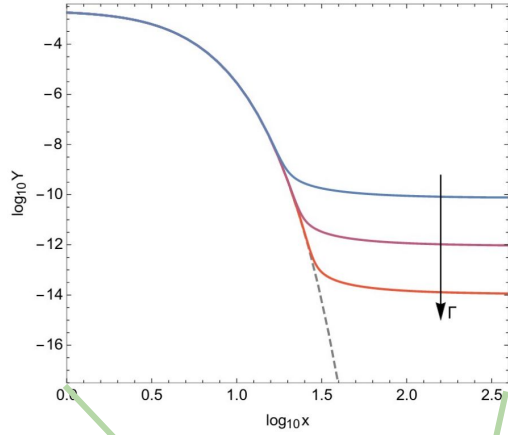


Freeze-out

$1/T$

Status of sub-GeV Dark Matter

Freeze-out



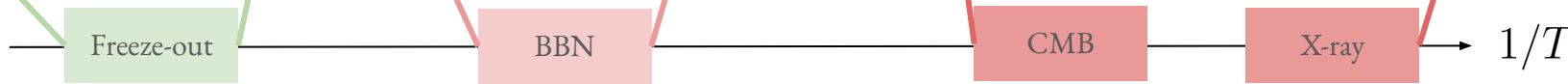
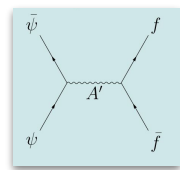
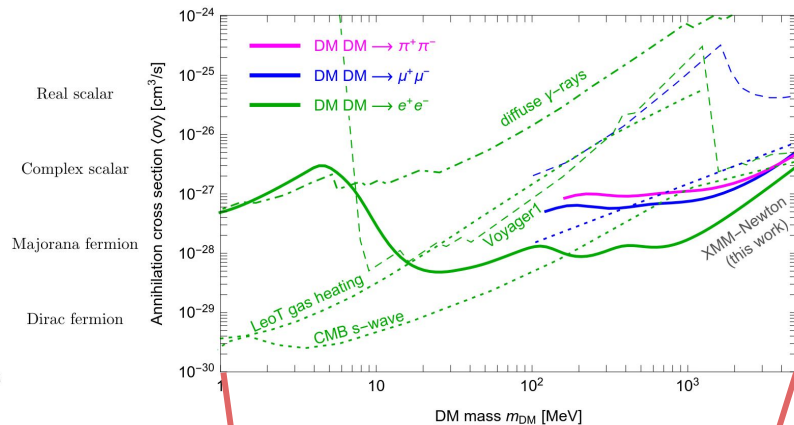
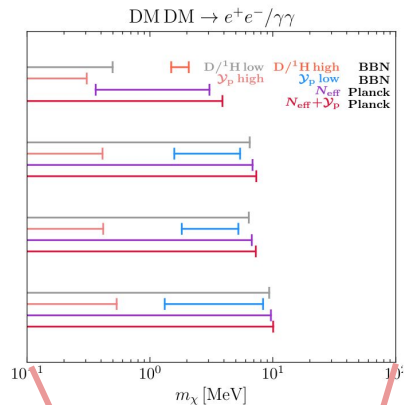
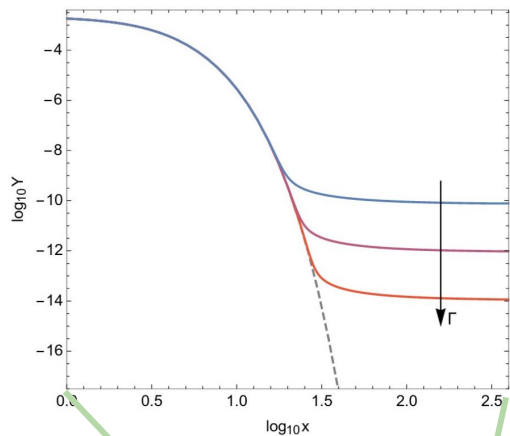
Freeze-out

BBN

$1/T$

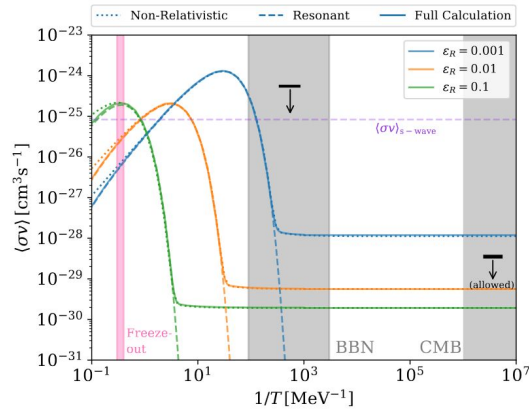
Status of sub-GeV Dark Matter

Freeze-out



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$$\epsilon_R \equiv \frac{m_{A'}^2 - 4m_{\text{DM}}^2}{4m_{\text{DM}}^2} \ll 1$$



- Asymmetry,

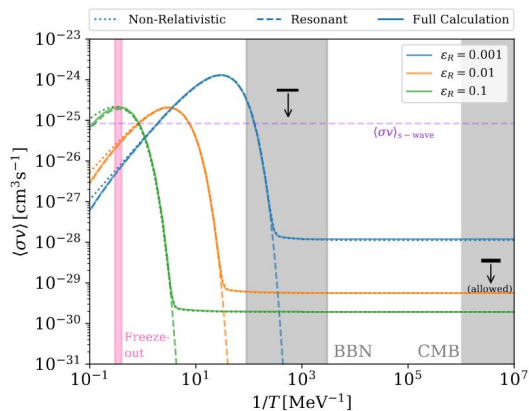
$$\eta_{\text{DM}} \equiv \frac{n_\chi - n_{\bar{\chi}}}{s} \neq 0$$

- Sub-dominant DM,

$$f_{\text{DM}} = \frac{\Omega_{\text{DM}} h^2}{\Omega_{\text{obs}} h^2} \leq 1$$

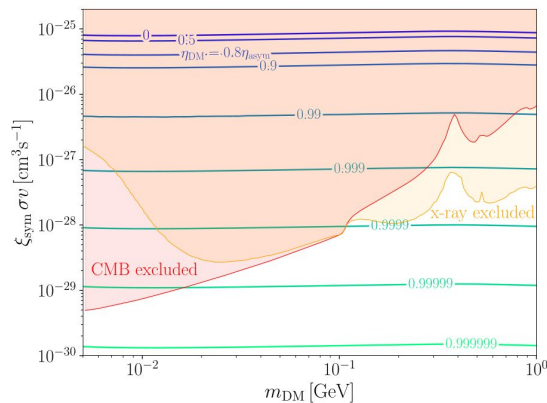
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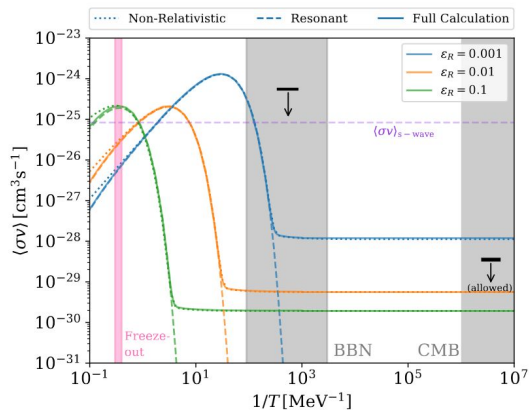


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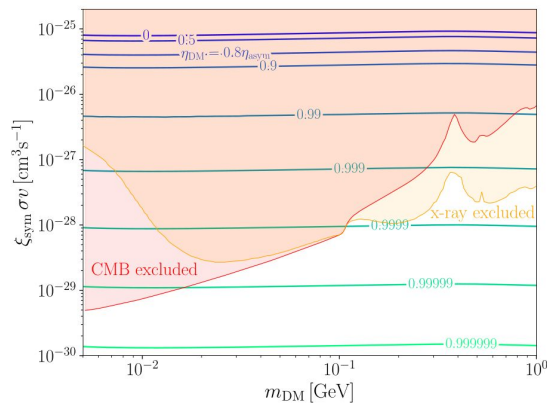
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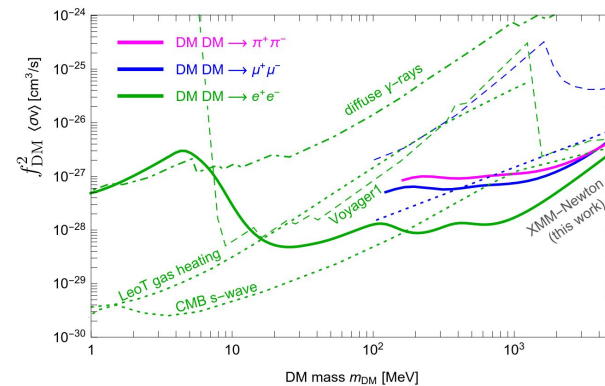
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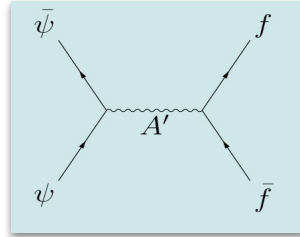
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+

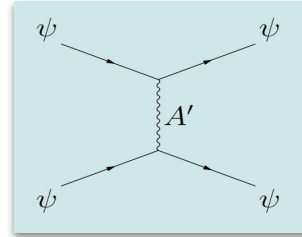
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Dark photon mass	$m_{A'}$
<i>or</i>	
Resonance parameter	ϵ_R
Kinetic mixing	κ
Asymmetry parameter	η_{DM}

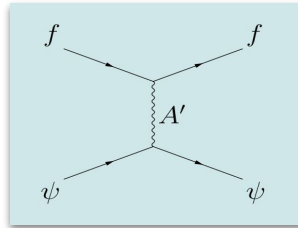
Indirect detection + Cosmology



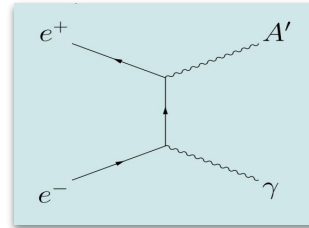
Bullet Cluster



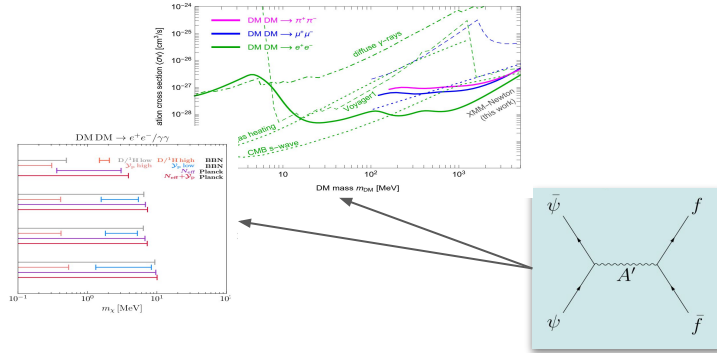
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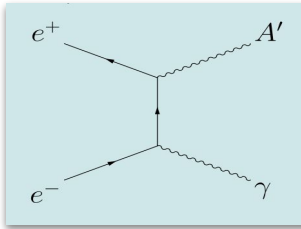
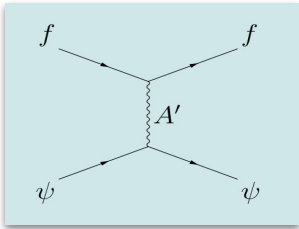
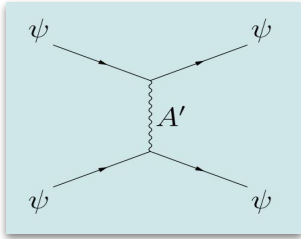
Accelerator experiments



Indirect detection + Cosmology



Bullet Cluster



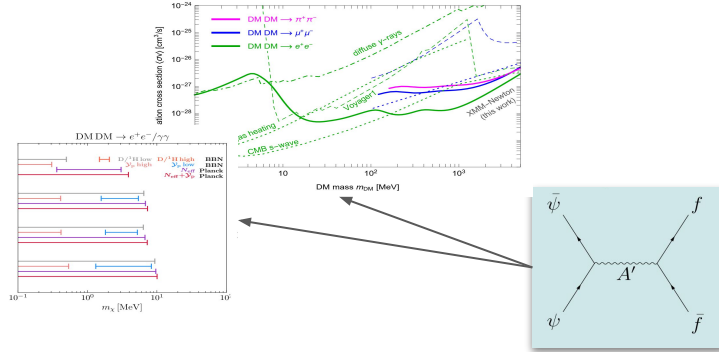
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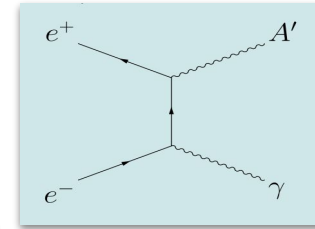
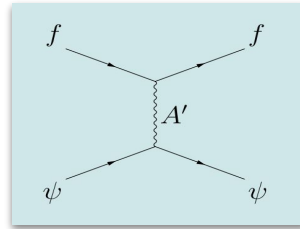
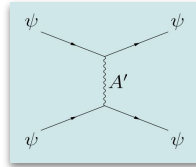
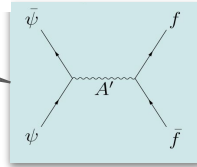
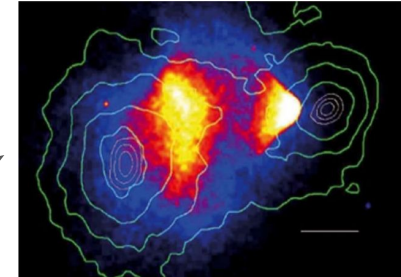
Status of sub-GeV Dark Matter

Signals and constraints

Indirect detection + Cosmology



Bullet Cluster



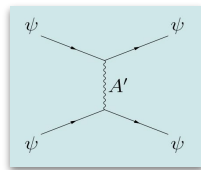
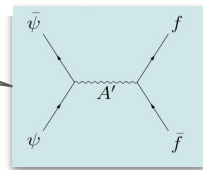
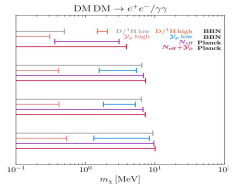
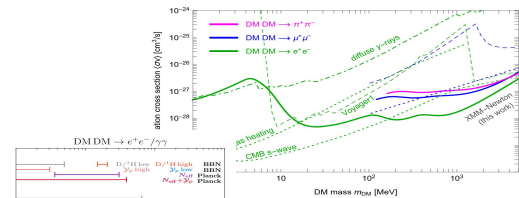
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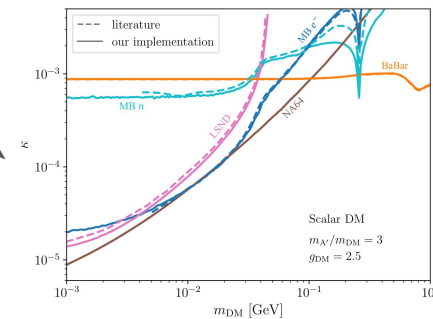
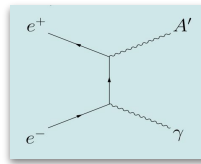
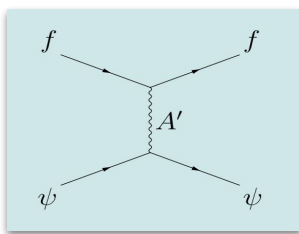
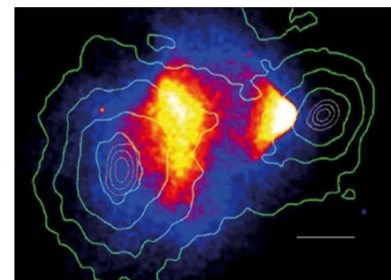
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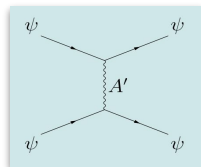
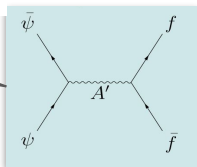
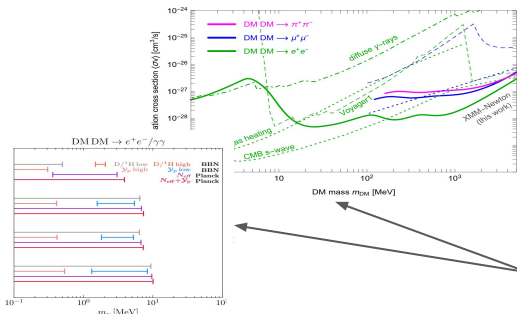
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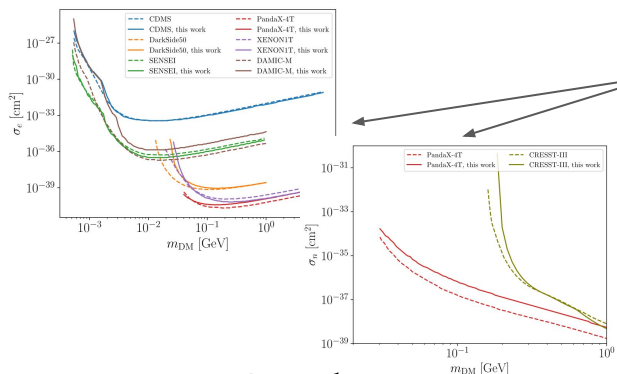
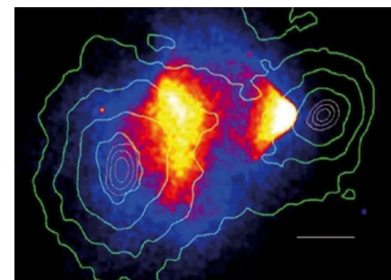
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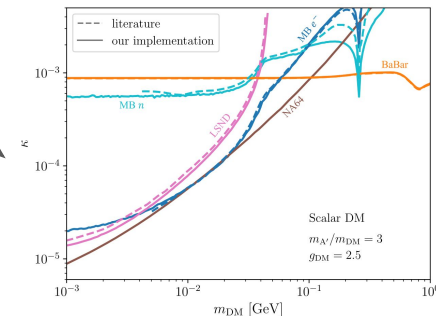
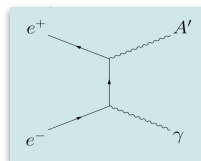
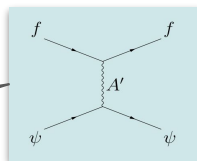
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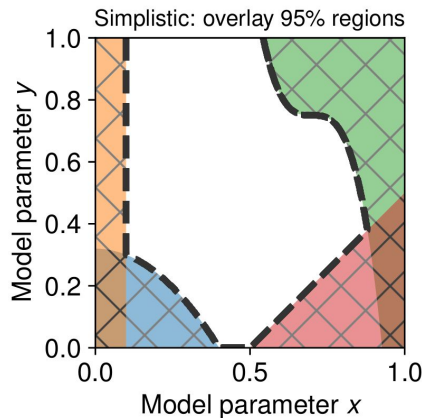
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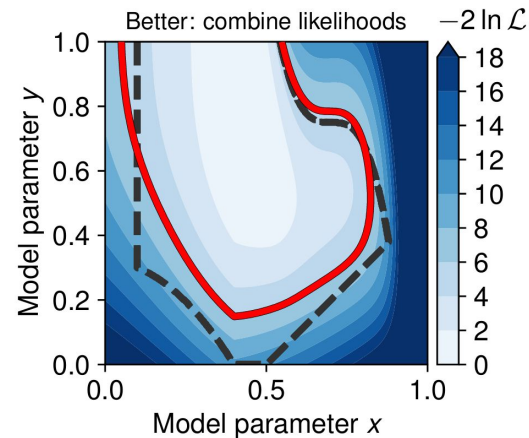
Accelerator experiments



- Simple overlay of constraints \rightarrow no proper statistical interpretation
- Global fits: combined likelihood

$$\mathcal{L} = \mathcal{L}_{\text{Collider}} \mathcal{L}_{\text{DD}} \mathcal{L}_{\text{ID}}$$

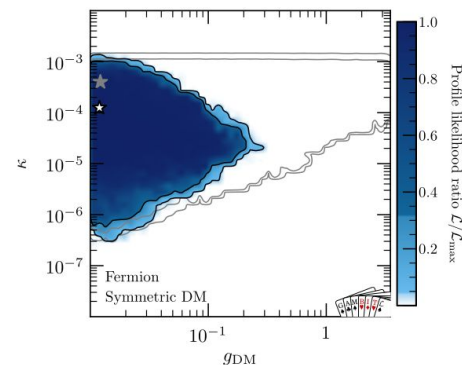
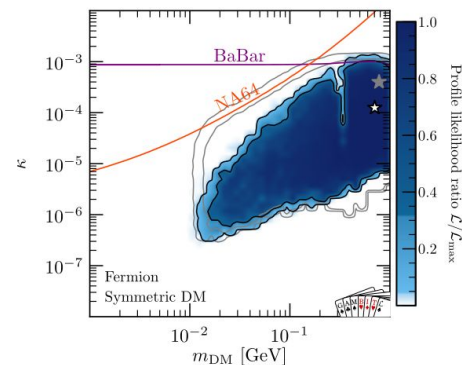
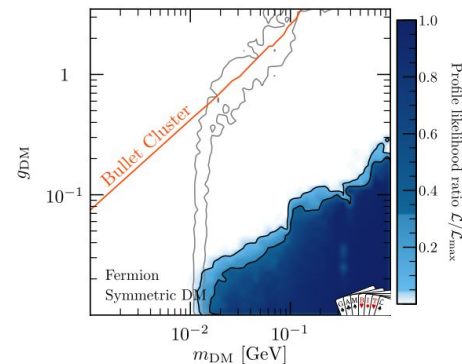
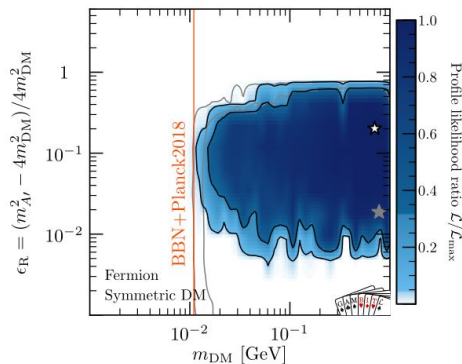
- Global fits with GAMBIT



Global And Modular Beyond the standard model Inference Tool (GAMBIT)

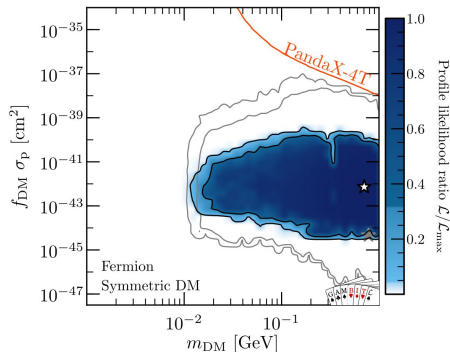
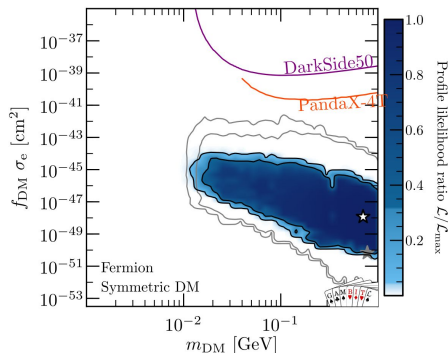
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- Sub-dominant DM: $\Omega_{\text{obs}} h^2 \leq 0.12$
 - Allows small resonance parameter, large couplings and masses
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- All DM: $\Omega_{\text{obs}} h^2 = 0.12$
 - Does not allow large couplings, fine-tuned parameter regions

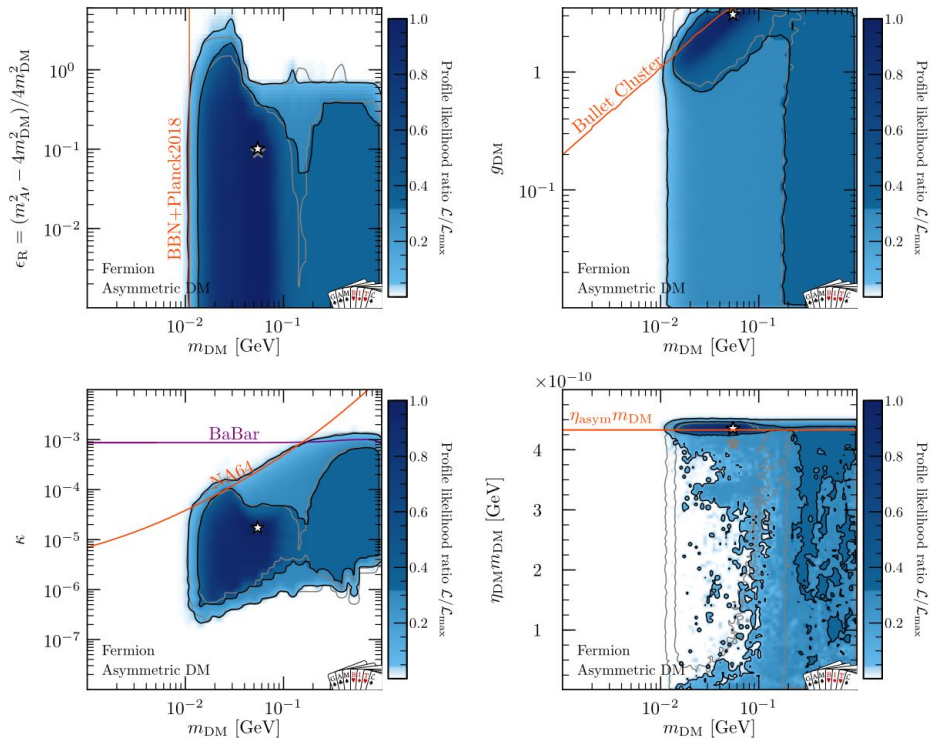


⇒ Symmetric fermionic DM (sub-dominant and all DM) - difficult to probe with current and future laboratory experiments



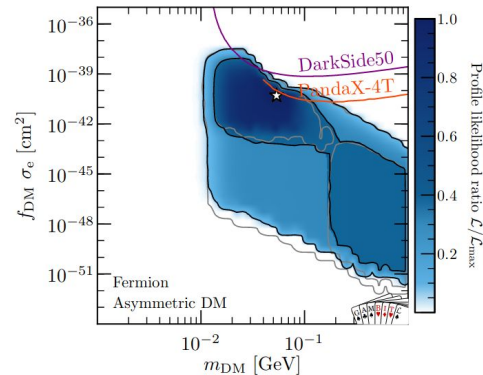
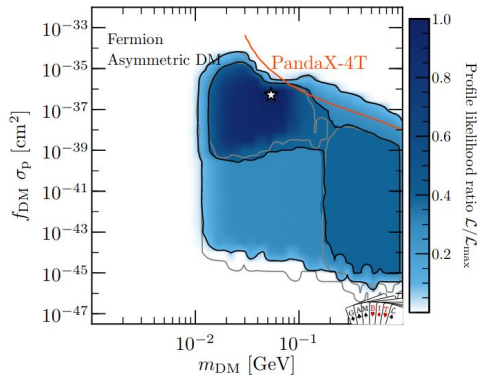
$$\eta_{\text{DM}} \neq 0$$

- All DM: $\Omega_{\text{obs}} h^2 = 0.12$
 - Large couplings allowed
 - Large asymmetry preferred
 - Contours coincide with sub-dominant DM



$$\eta_{\text{DM}} \neq 0$$

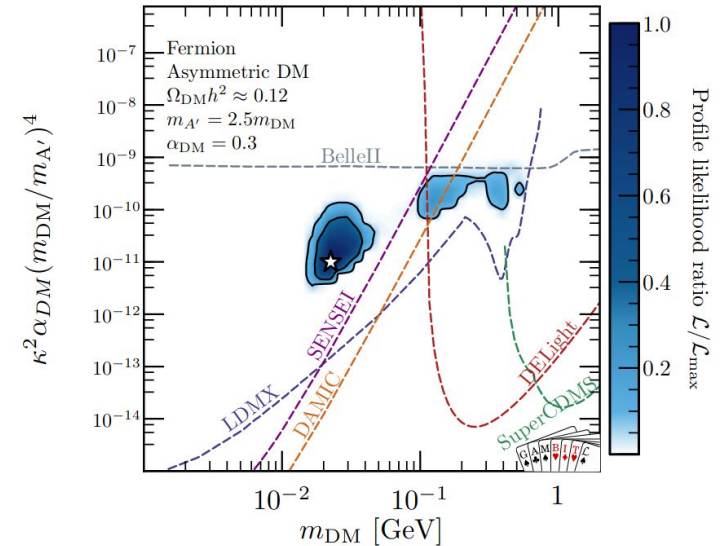
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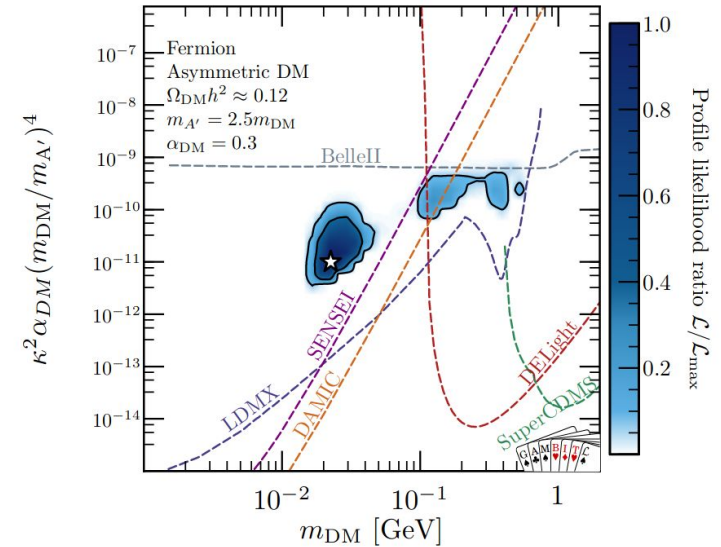
⇒ Asymmetric fermionic DM - discoverable!



- Sub-GeV DM with coupling to a massive dark photon can be a **thermal relic**
- Velocity-independent annihilation strongly constrained by CMB and X-rays
- Solutions: Resonance , particle-antiparticle asymmetry
- **Discoverable!**



- Sub-GeV DM with coupling to a massive dark photon can be a thermal relic
- Velocity-independent annihilation strongly constrained by CMB and X-rays
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- Discoverable!



THANKS! QUESTIONS?

APPENDIX

Parameter name	Symbol	Unit	Range
Kinetic mixing	κ	–	$[10^{-8}, 10^{-2}]$
Dark sector coupling	g_{DM}	–	$[10^{-2}, \sqrt{4\pi}]$
Asymmetry parameter	η_{DM}	–	$[0, 10^{-9} \text{ GeV}/m_{\text{DM}}]$
Dark matter mass	m_{DM}	MeV	$[1, 1000]$
Dark photon mass	$m_{A'}$	MeV	$[2, 6000]$ with $m_{A'} \geq 2m_{\text{DM}}$
<i>or</i>			
Resonance parameter	ϵ_R	–	$[10^{-3}, 8]$

Nuisance parameters: $\rho_0, v_0, v_{\text{esc}}$