

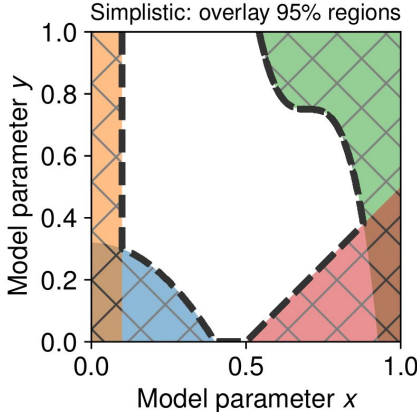


Global fits of sub-GeV dark matter models with GAMBIT

Sowmiya Balan

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

[JCAP01\(2025\)053](#)



AbdusSalam et al, arXiv:2012.09874

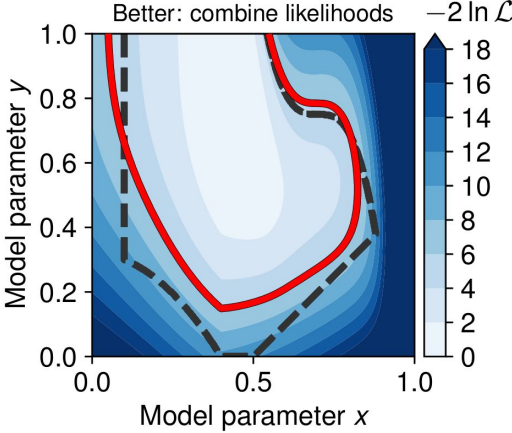
- Simple overlay of constraints → no proper statistical interpretation
- Global fits: combined likelihood

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

- Global fits with GAMBIT



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



AbdusSalam et al, arXiv:2012.09874

Model - Sub-GeV fermionic DM

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

$$\bar{\psi}(i\cancel{D} - m_{\text{DM}})\psi + g_{\text{DM}}A'^{\mu}\bar{\psi}\gamma_{\mu}\psi$$

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

$$\frac{\kappa}{2}F_{\mu\nu}F'^{\mu\nu} \longrightarrow \kappa e A'^{\mu} \sum_f q_f \bar{f}\gamma_{\mu}f$$

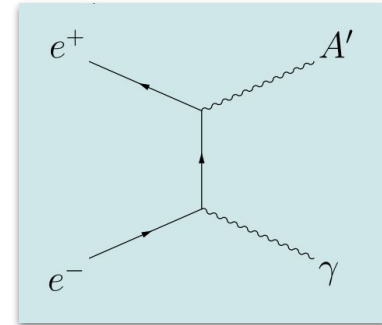
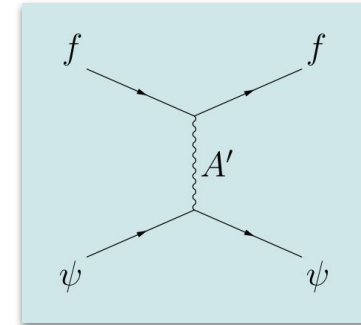
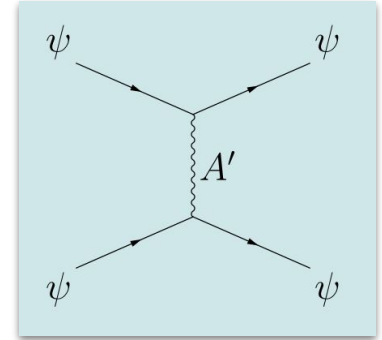
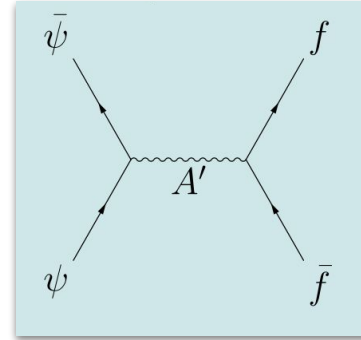
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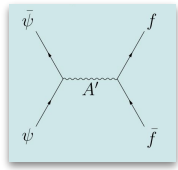
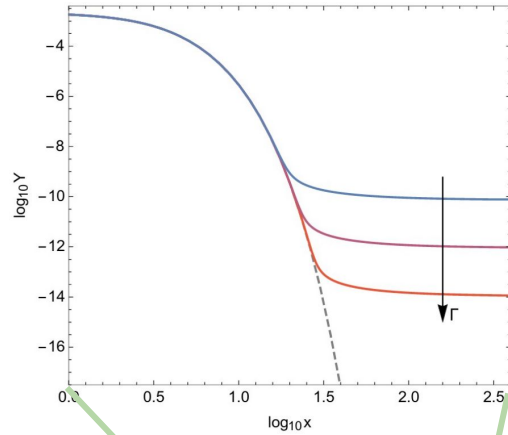
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Status of sub-GeV dark matter

Sowmiya Balan, Taylor R. Gray, Felix Kahlhoefer, Torsten Bringmann and others

Challenges to freeze-out



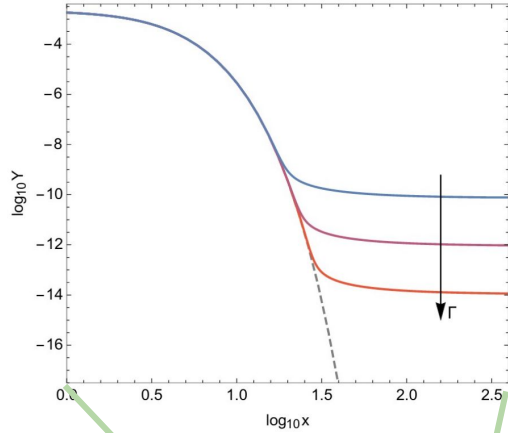
Freeze-out

$1/T$

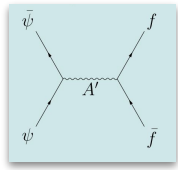
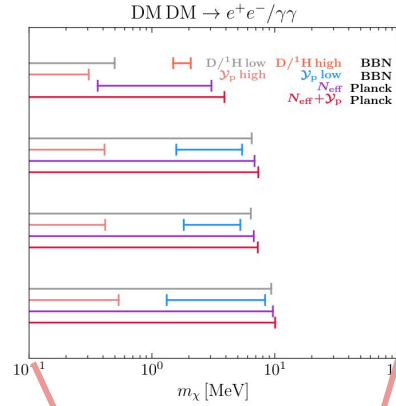
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Challenges to freeze-out



Depta et al, arXiv:1901.06944



Freeze-out

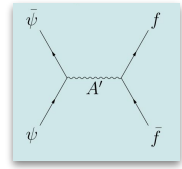
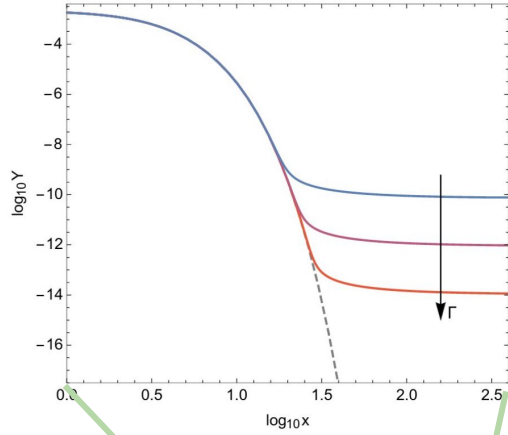
BBN

$1/T$

Status of sub-GeV dark matter

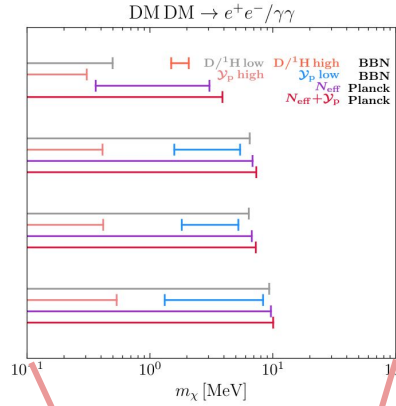
Sowmiya Balan, Taylor R. Gray, Felix Kahlhoefer, Torsten Bringmann and others

Challenges to freeze-out



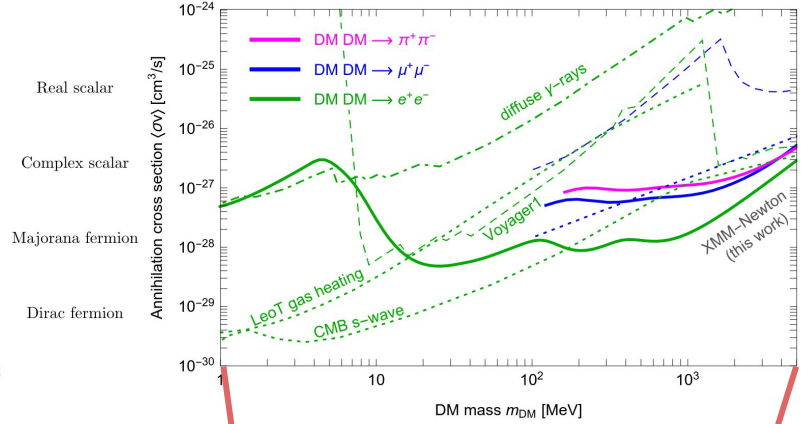
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BBN

Cirelli et al, arXiv:2303.08854



CMB

X-ray

1/T

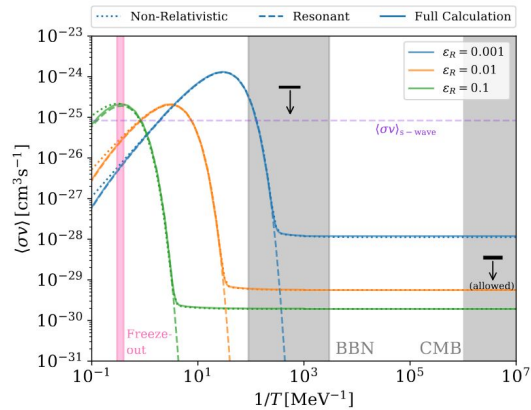
Status of sub-GeV dark matter

Sowmiya Balan, Taylor R. Gray, Felix Kahlhoefer, Torsten Bringmann and others

Possible solutions

- Resonance,

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



Bernreuther et al, arXiv:2010.14522

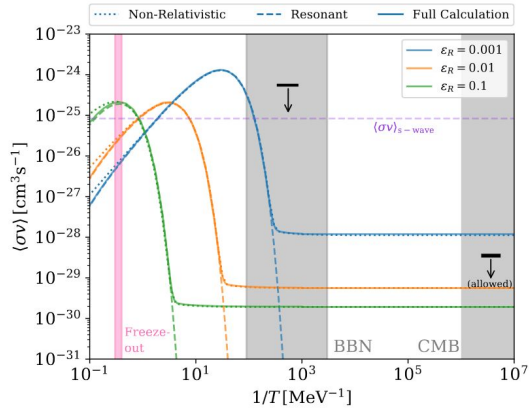
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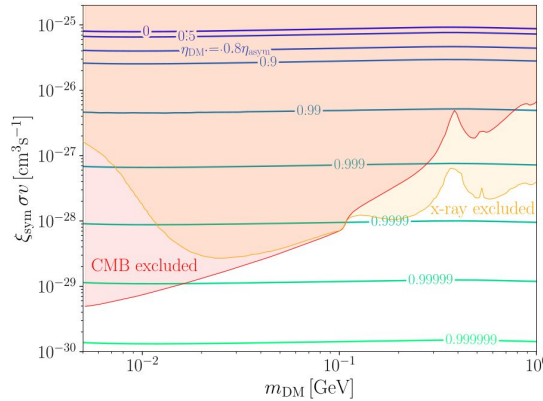
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- Asymmetry,

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



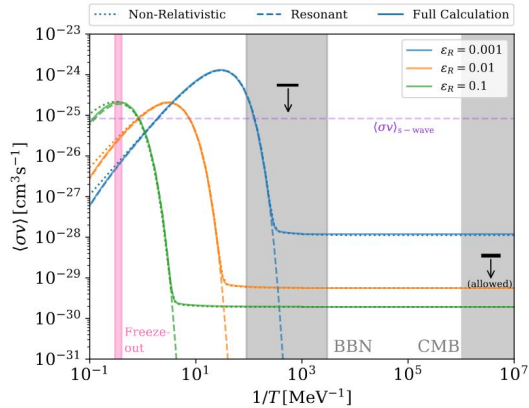
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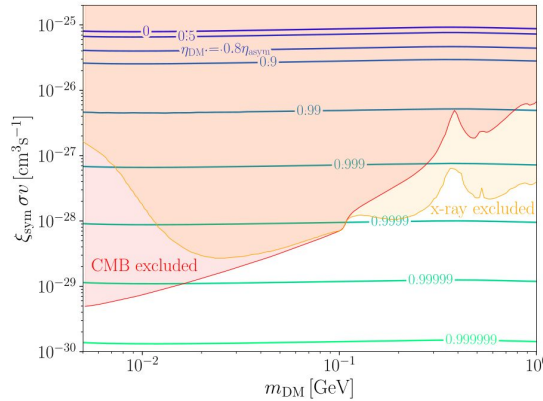
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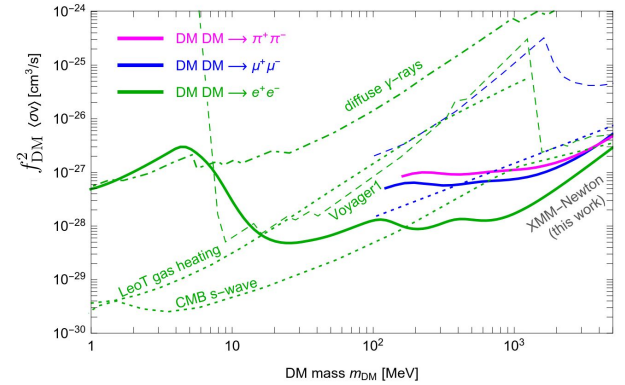
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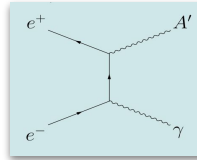
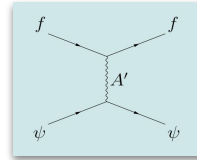
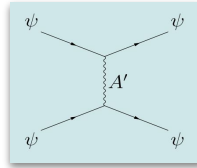
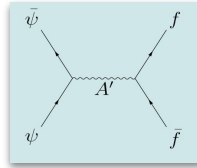
- Sub-dominant DM,

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



Cirelli et al, arXiv:2303.08854

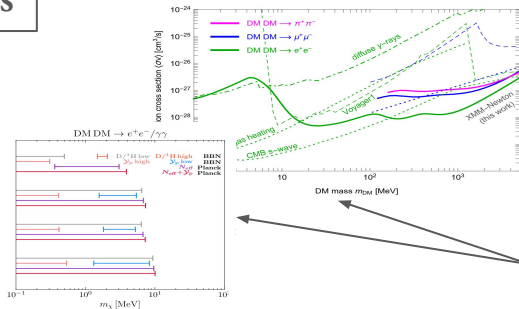
Constraints



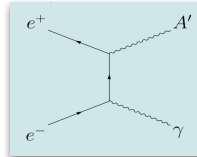
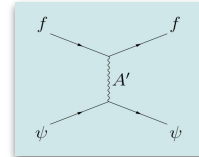
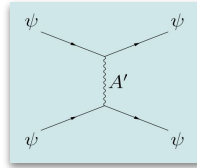
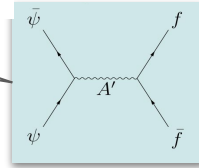
Status of sub-GeV dark matter

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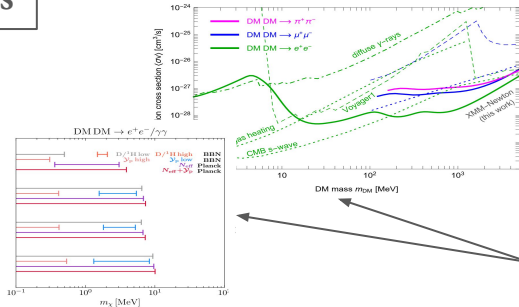
Indirect detection + Cosmology



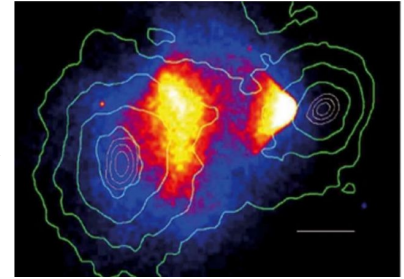
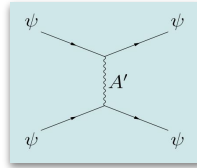
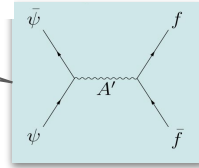
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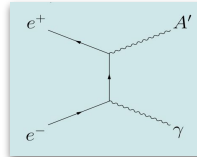
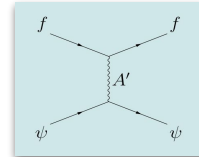
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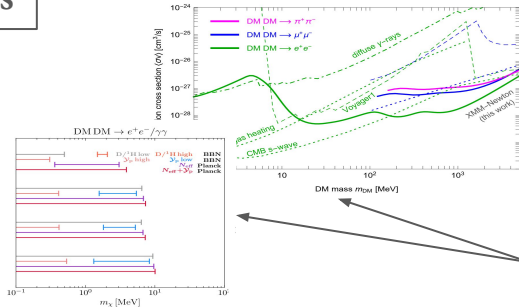
Bullet Cluster



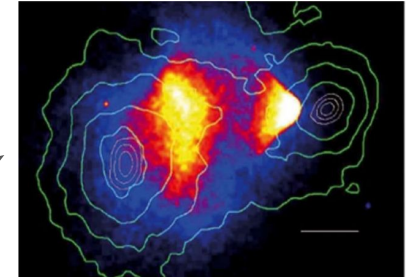
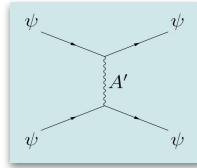
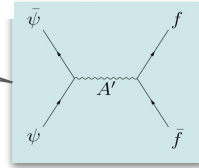
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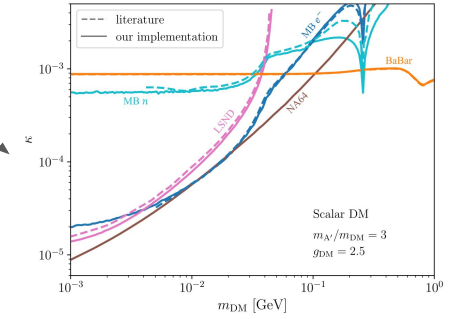
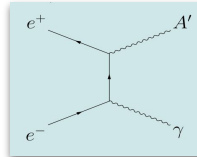
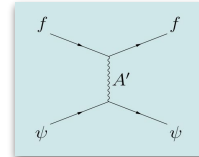
Constraints



Indirect detection + Cosmology



Bullet Cluster

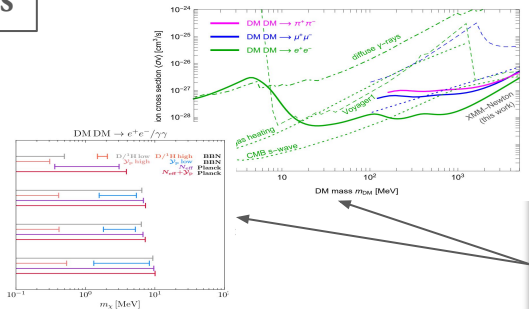


Accelerator experiments

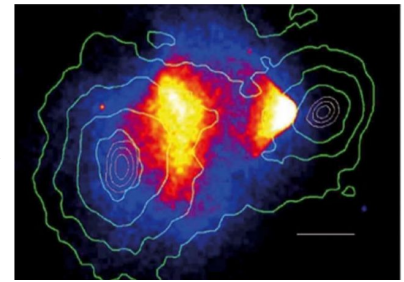
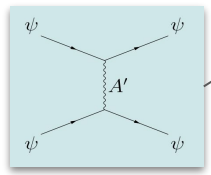
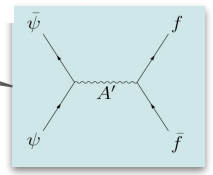
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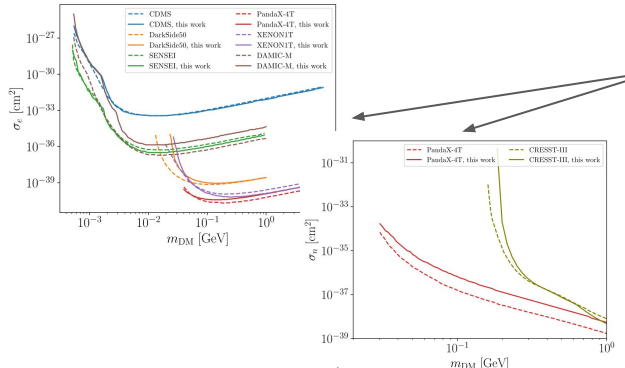
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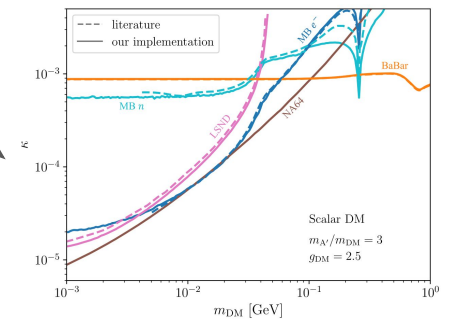
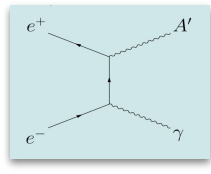
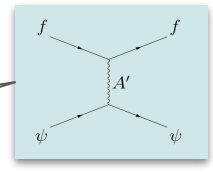
Indirect detection + Cosmology



Bullet Cluster



Direct detection



Accelerator experiments

Status of sub-GeV dark matter

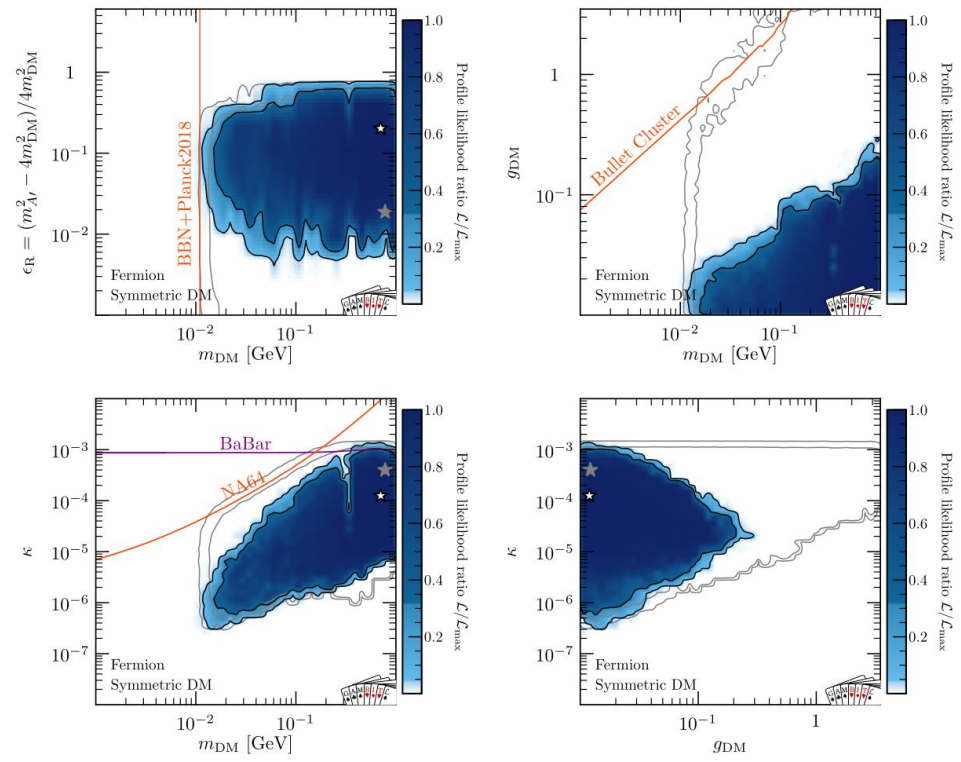
Sowmiya Balan, Taylor R. Gray, Felix Kahlhoefer, Torsten Bringmann and others

Results: Symmetric dark matter

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

- Sub-dominant DM: $\Omega_\psi h^2 \leq 0.12$
 - Allows small resonance parameter, large couplings and masses

- All DM: $\Omega_\psi h^2 = 0.12$
 - Does not allow large couplings, fine-tuned parameter regions



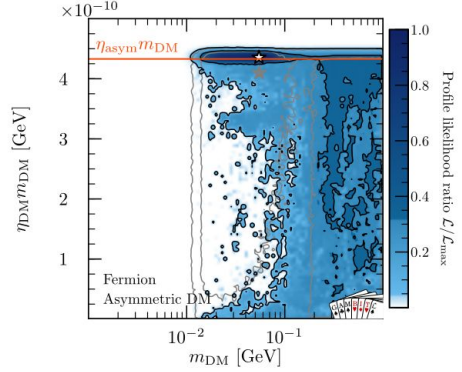
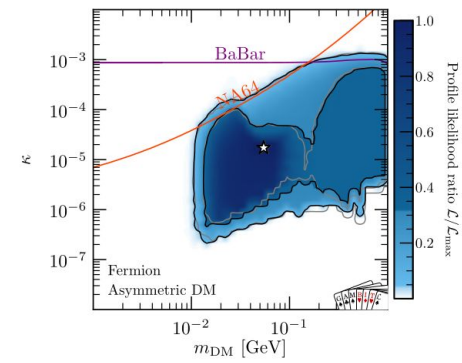
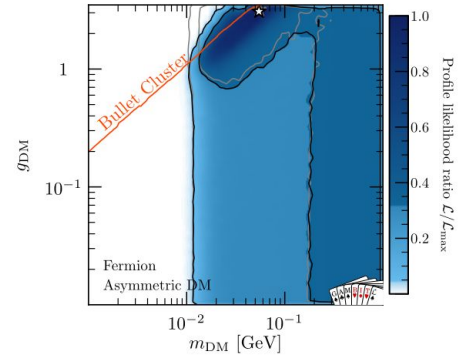
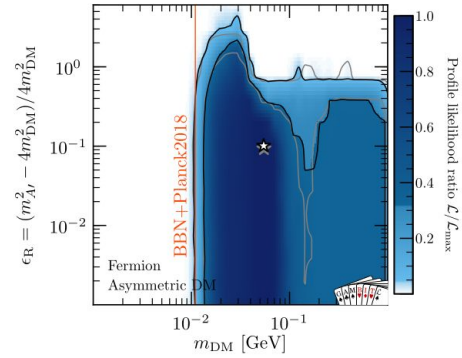
Status of sub-GeV dark matter

Sowmiya Balan, Taylor R. Gray, Felix Kahlhoefer, Torsten Bringmann and others

Results: Asymmetric dark matter

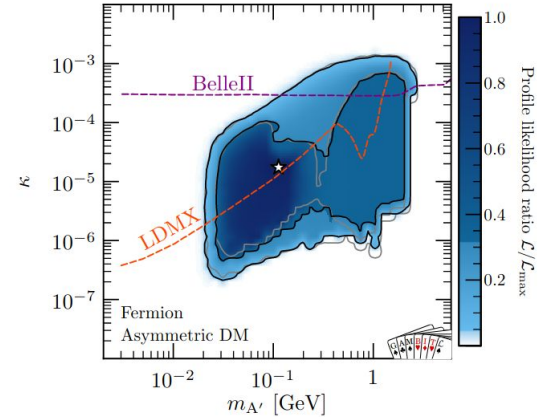
$$\eta_{\text{DM}} \neq 0$$

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



Conclusions

- 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
- Bayesian model comparison: **Asymmetric DM preferred**
- **Discoverable!**



BACKUP

GAMBIT: The Global And Modular BSM Inference Tool

gambitbsm.org

github.com/GambitBSM

EPJC 77 (2017) 784

arXiv:1705.07908

- Extensive model database, beyond SUSY
- Fast definition of new datasets, theories
- Extensive observable/data libraries
- Plug&play scanning/physics/likelihood packs
- Various statistical options (frequentist /Bayesian)
- Fast LHC likelihood calculator
- Massively parallel
- Fully open-source



Members of: ATLAS, Belle-II, CLiC, CMS, CTA, Fermi-LAT, DARWIN, IceCube, LHCb, SHiP, XENON

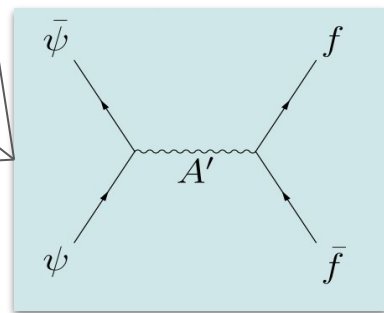
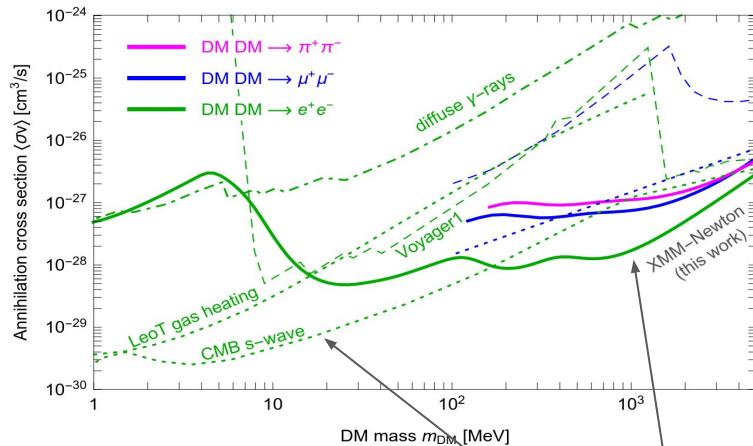
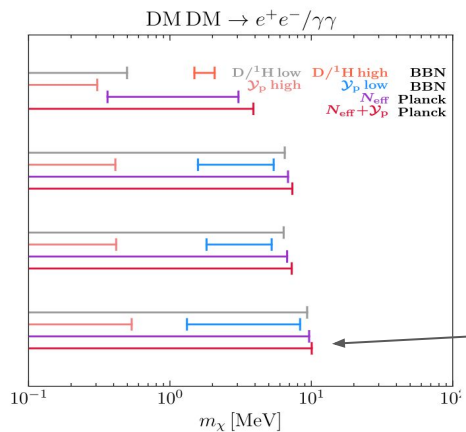
Authors of: BubbleProfiler, Capt'n General, Contur, DarkAges, DarkSUSY, DDCalc, DirectDM, Diver, EasyScanHEP, ExoCLASS, FlexibleSUSY, gamLike, GM2Calc, HEPLike, IsaTools, MARTY, nuLike, PhaseTracer, PolyChord, Rivet, SOFTSUSY, SuperIso, SUSY-AI, xsec, Vevacious, WIMPSim

Recent collaborators: V Ananyev, P Athron, N Avis-Kozar, C Balázs, A Beniwal, LL Braseth, T Bringmann, A Buckley, J Butterworth, JE Camargo-Molina, C Chang, J Cornell, M Danninger, A Fowlie, T Gonzalo, W Handley, S Hoof, A Jueid, F Kahlhoefer, A Kvellestad, M Lacroq, C Lin, M Lucente, FN Mahmoudi, DJE Marsh, G Martinez, H Pacey, MT Prim, T Procter, F Rajec, A Raklev, R Ruiz, A Scaffidi, P Scott, W Shorrocks, C Sierra, P Stöcker, W Su, J Van den Abeele, A Vincent, M White, A Woodcock, Y Zhang ++

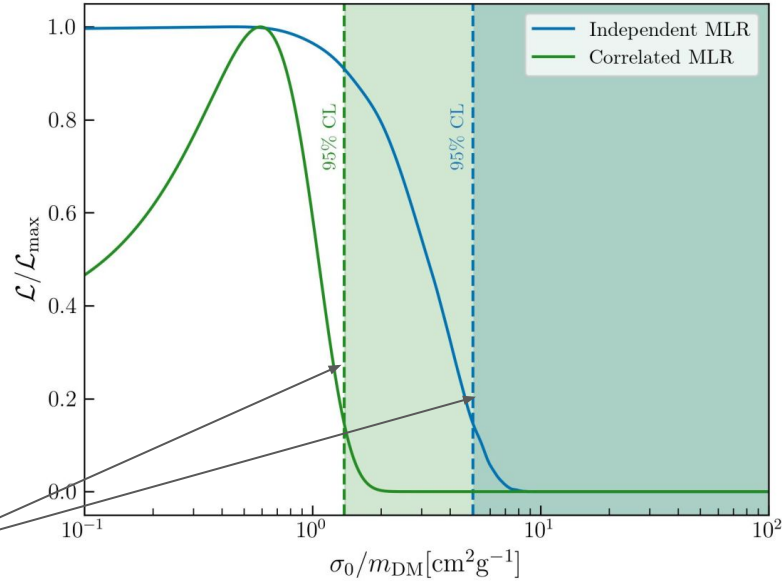
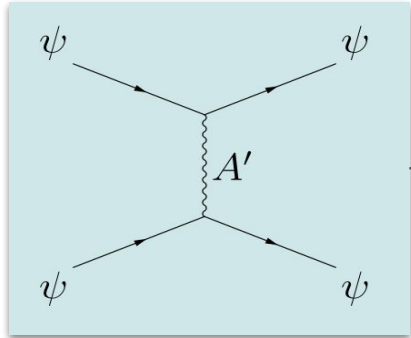
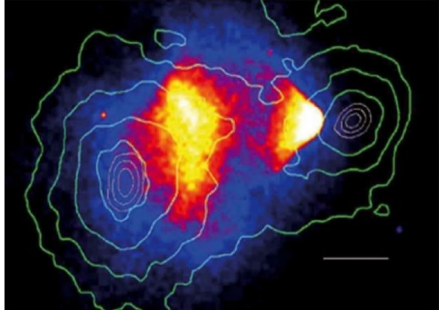
Status of sub-GeV Dark Matter

Cosmological and ID constraints

- BBN: $m_{\text{DM}} \gtrsim 10 \text{ MeV}$
- CMB + X-ray: strong late universe annihilation constraints



Bullet Cluster constraints

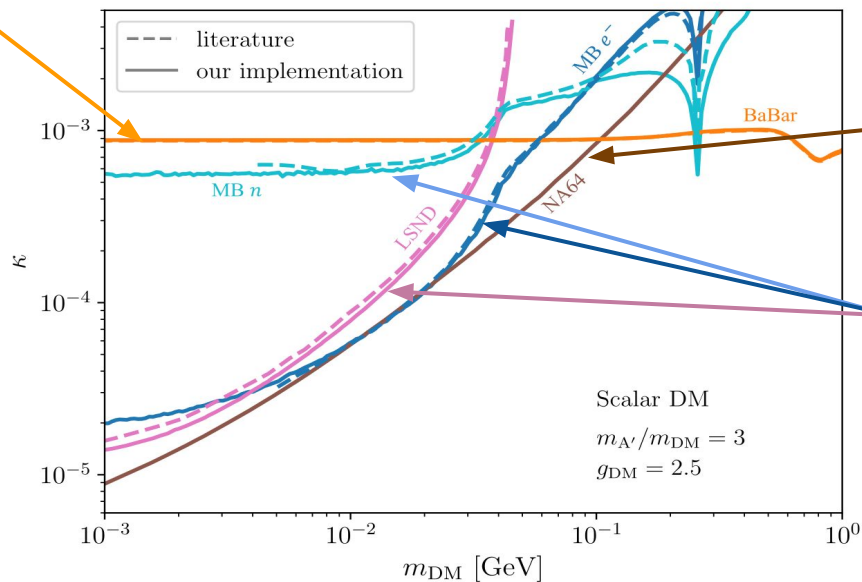
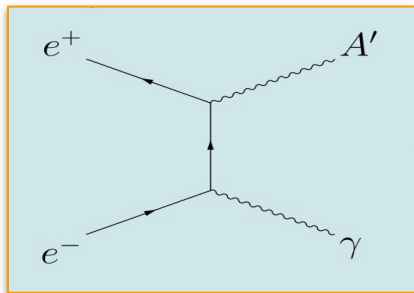


- Based on sub-cluster survival in Bullet Cluster
- Symmetric DM + isotropic, velocity-independent cross-section:

$$\sigma_0/m_{\text{DM}} < 1.4 \text{ cm}^2 \text{g}^{-1}$$

Status of sub-GeV Dark Matter

Accelerator experiments



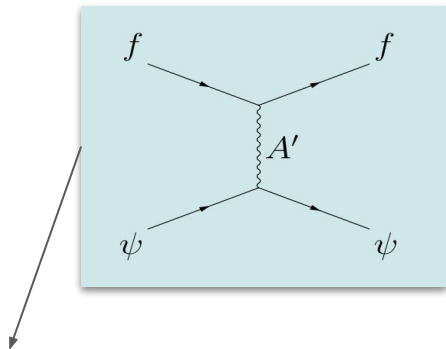
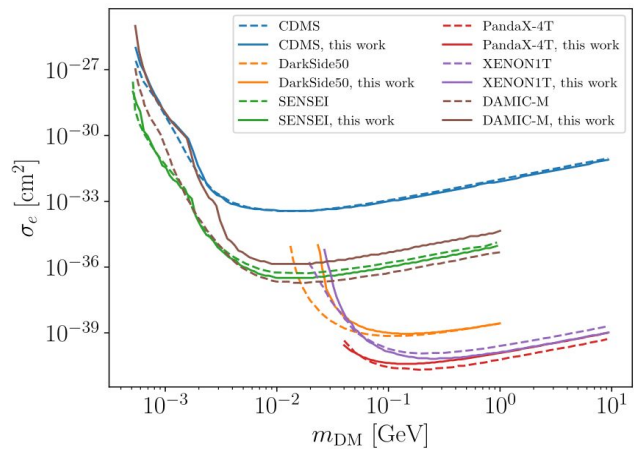
- Missing energy events

$$e^- Z \rightarrow e^- Z A'$$

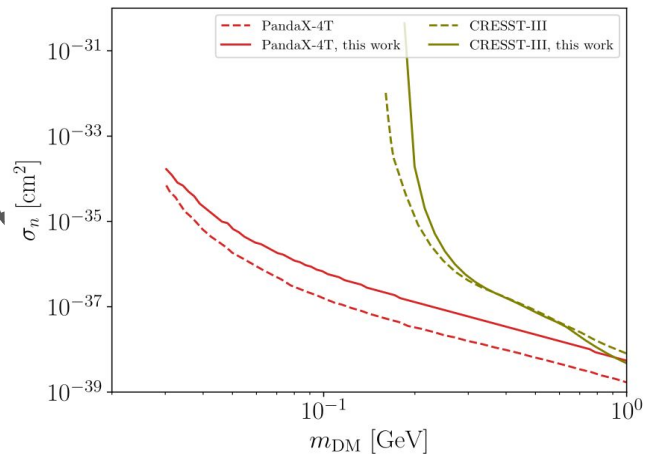
- DM scattering events

$$\pi^0, \eta \rightarrow \gamma + A', A' \rightarrow \chi \bar{\chi}$$

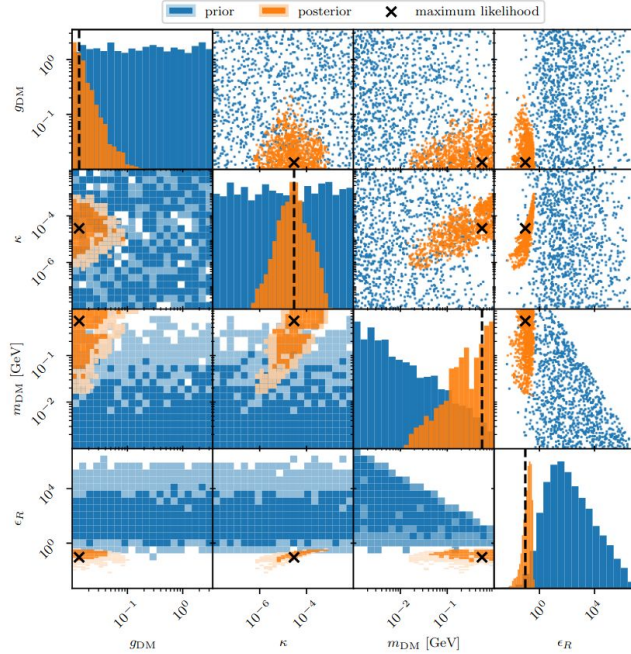
- DM - electron scattering



- DM - nucleus scattering



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



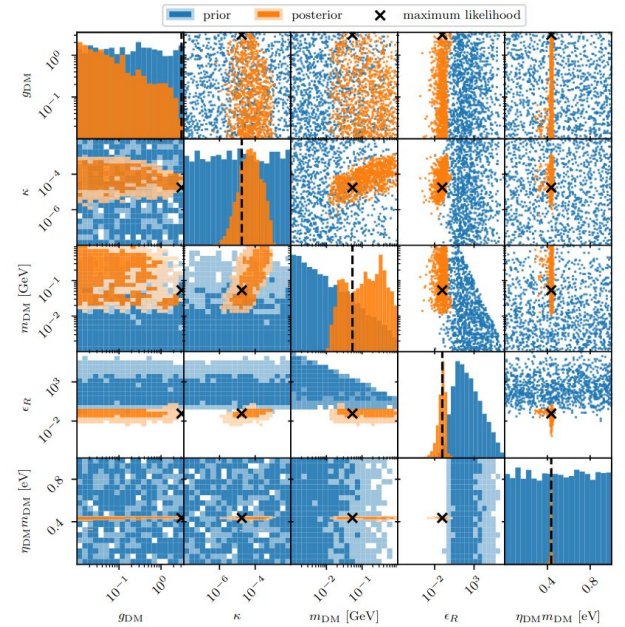
$$\Omega_{\text{obs}} h^2 = 0.12$$

Fermion ψ , symmetric $\eta_{\text{DM}} = 0$, $\Omega_{\text{DM}} h^2 \approx 0.12$

Bayes factor:

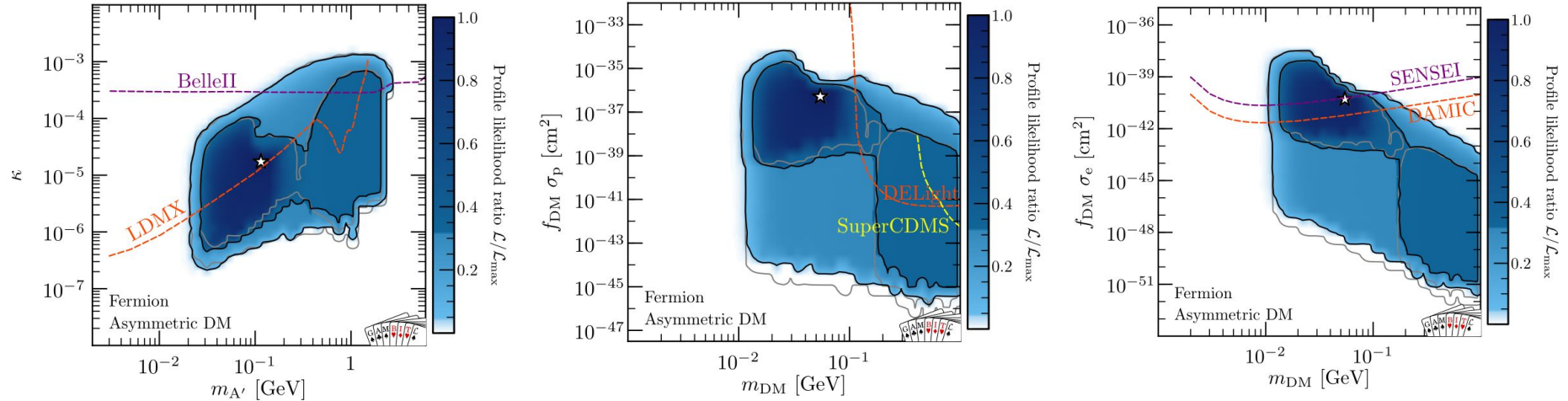
$$\frac{\mathcal{Z}_{\text{asym}}}{\mathcal{Z}_{\text{sym}}} = 15.6$$

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



Fermion ψ , asymmetric $\eta_{\text{DM}} \neq 0$, $\Omega_{\text{DM}} h^2 \approx 0.12$

- Allowed parameter regions can be probed by future laboratory experiments



- Proposed new benchmark point within allowed parameter regions - fully explored by future experiments

