A Solar Probe of Dark Matter Decay in the Galaxy

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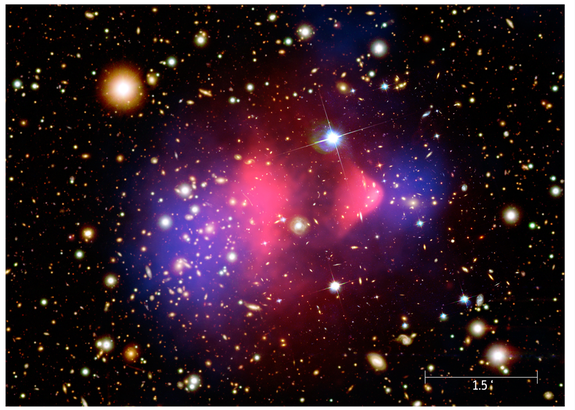
Sheffield, UK

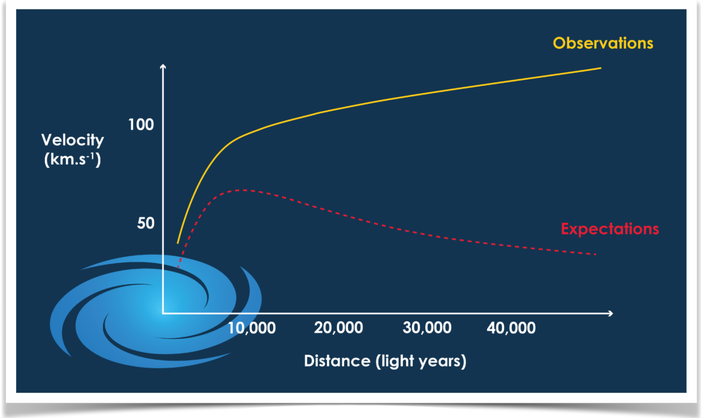
Based on 2604.00091, **MD** & Shyam Balaji

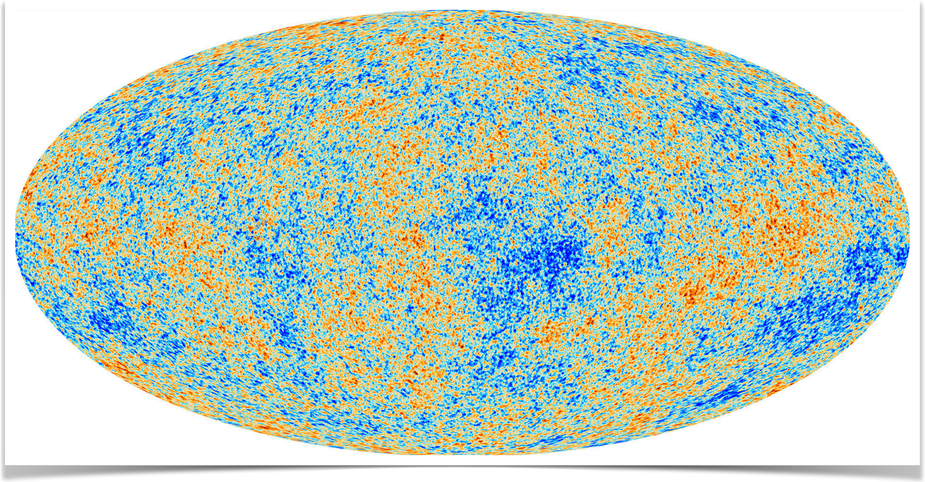
Maximilian Detering, 23/06/2026

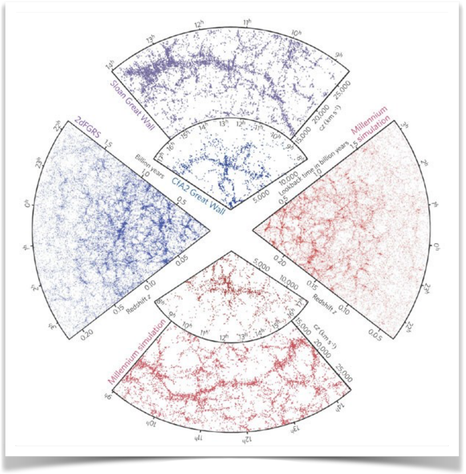
Dark Matter

Evidence and Searches



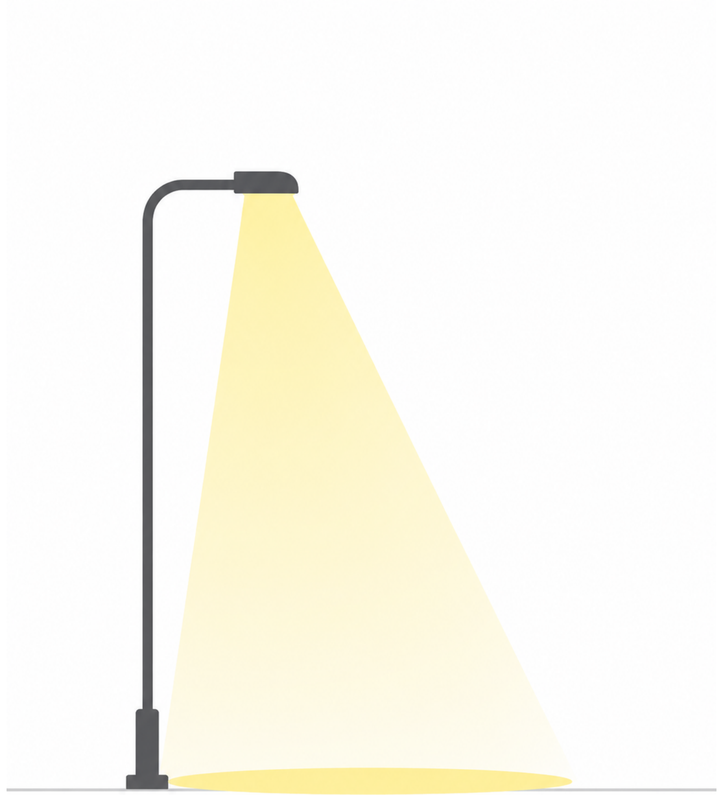






Why should we look for decaying dark matter?

because we can



Why should we look for decaying dark matter?

because we can

doesn't mean we should

- Absolute stability hard to justify
  - In the SM, consequence of charge conservation and accidental symmetries
  - Why should this be true for DM?
- Planck-suppressed operators or suppressed couplings can yield cosmological lifetimes
- Many UV-complete models predict unstable DM

Indirect Detection

Decaying Dark Matter

Various kinds of decaying dark matter searches exist:

- Indirect probes leverage DM annihilation or decay into SM messengers
  - γ-rays generally prized for directionality and clean transport
  - Standard targets are galactic halos, dwarf galaxies and extragalactic sources
- Common bottleneck: limited diffuse backgrounds + modelling systematics that worsen toward faint signals
- Question: Is there a target where the signal scales differently?

Decaying Dark Matter Searches

Galactic versus solar

- The universal signature: DM decay injects $e^{\pm}$ throughout the Galactic halo*

  ➡ These inverse-Compton scatter ambient photons → γ rays

- Importantly, the IC yield along a line-of-sight scales not just with the DM column but with the photon column:

$$\text{Signal} \sim \int Q_\chi \, n_\gamma \, \mathrm{d}\ell_{\mathrm{LOS}} \,, \qquad Q_\chi \sim \frac{\rho_\chi}{m_\chi \tau_\chi} \frac{dN}{dE}$$

Galactic indirect searches
+ long column
- faint photon field
- diffuse backgrounds

⟷

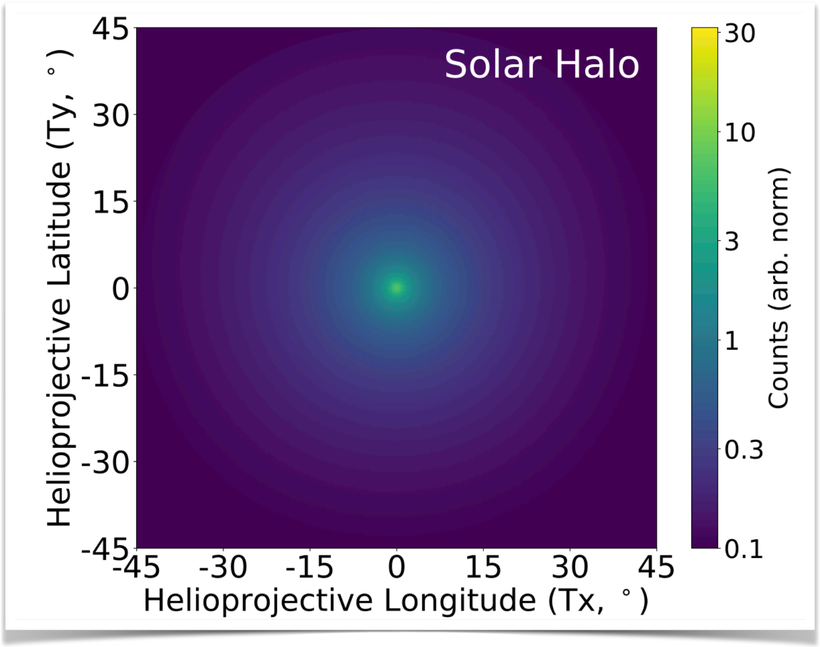
Solar halo measurement
- short column
+ localised source
+ intense photon field

*except for prompt decay into $\gamma\gamma$

Solar γ-ray halo

Our laboratory

Background-subtracted model



Tim Linden et al., *Phys. Rev. D* 112 (2025) 10, 103030

A *new, clean* probe:

- solar γ-ray halo has been robustly detected using 15 years of *Fermi*-LAT data
- signal scales with *well-known* photon field
- *localised* source and known backgrounds
- Systematically distinct from galactic-diffuse and direct charged-particle searches

From DM-decay to the γ-ray halo

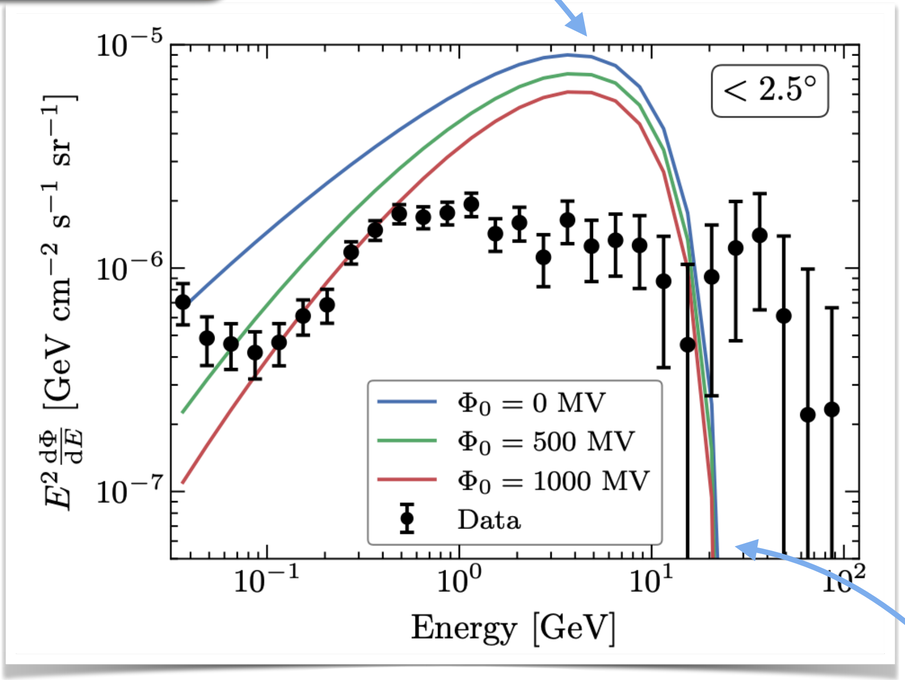
- **Injection:** DM decay sources $e^{\pm}$ flux throughout the halo, with spectrum set by m_χ, τ_χ and decay channel
- **Propagation:** galactic diffusion and solar modulation in the heliosphere shape the $e^{\pm}$ flux
- **Target:** solar thermal photons spectrum, $n_\gamma \sim r^{-2}$ and $E_\gamma \sim T_\odot$
- **Inverse Compton scattering:** relativistic $e^{\pm}$ up-scatter photons into γ rays
- **Observable:** line-of-sight integral over emissivity

$$I_\gamma(E_\gamma, \psi) = \int_{\mathrm{LOS}} \mathrm{d}\ell \int \mathrm{d}E_e \, \frac{\mathrm{d}n_e}{\mathrm{d}E_e} \, n_\gamma(r) \, \frac{\mathrm{d}\sigma_{\mathrm{KN}}}{\mathrm{d}E_\gamma}$$

DM-injected ICS component

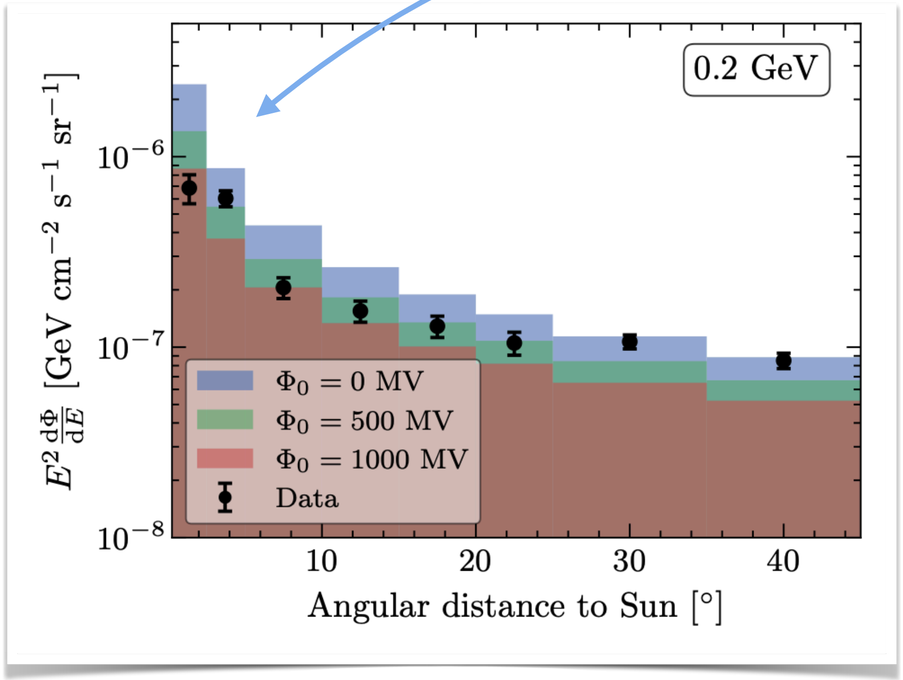
Signal morphology

Peak energy set by DM mass and solar blackbody spectrum



$$E_{\text{peak}} \sim \frac{\left(\frac{m_\chi}{m_e}\right)^2 E_\gamma}{1 + \frac{m_\chi E_\gamma}{m_e^2}}$$

Surface brightness rises steeply towards the Sun



$$E^2 \frac{d\Phi}{dE} \propto \theta^{-1}$$

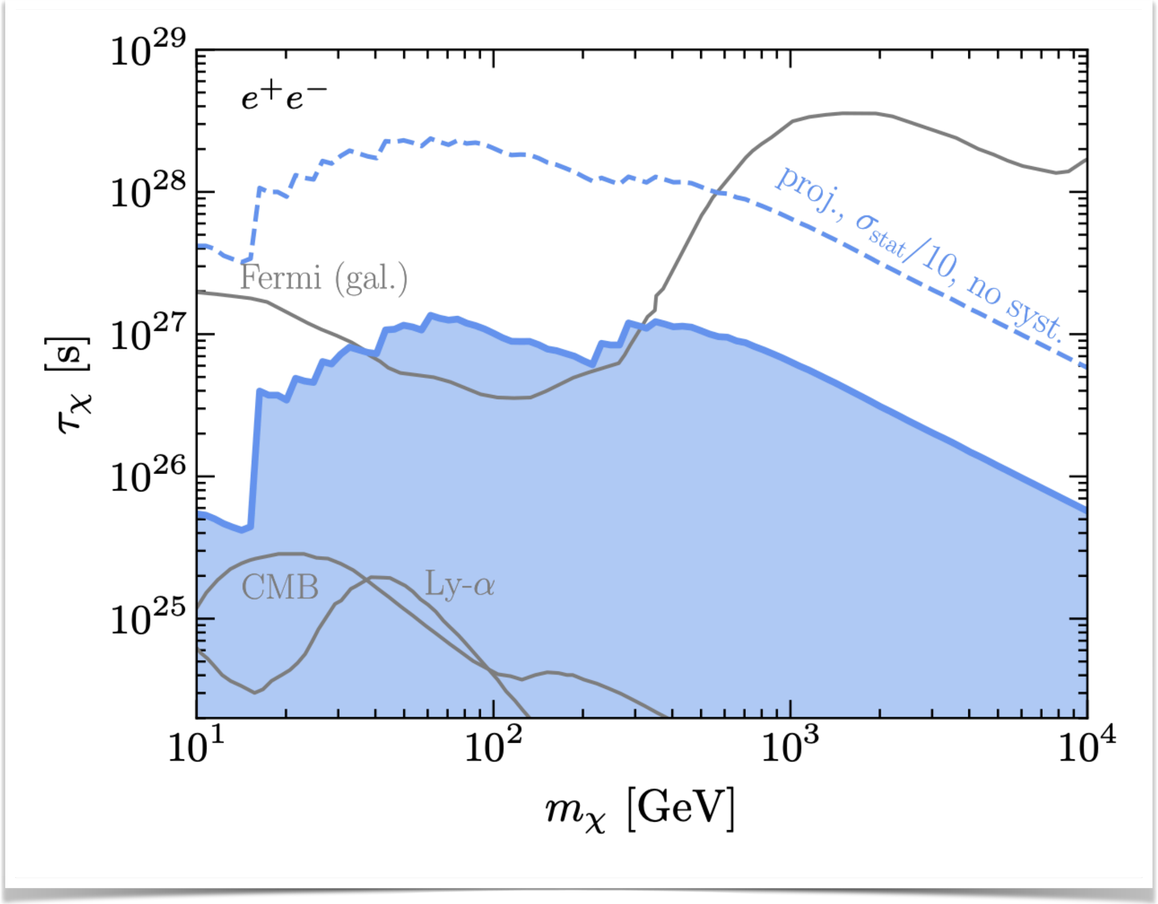
Kinematic cutoff and suppressed cross section at high energies

Method

Inference pipeline

- **Data:** 15 yr Fermi-LAT events around the Sun; moving-source analysis tracking the Sun's path, with a data-driven background model tailored to the solar region
- **Model:**
  - **Signal:** for each $\{m_\chi, \tau_\chi, \text{channel}\}$, build the predicted ICS halo
  - **Background**: astrophysical electron and positron fluxes
  - **Solar modulation:** modulation of signal and background fluxes
- **Fit:** joint likelihood over the energy bins and annuli around the Sun; profiling nuisance parameters (background normalisation, modulation)
- Note: Extended halo is important as signal drops with elongation angle similar to data + inner heliosphere has largest modelling uncertainty

Results



- Solar ICS halo excludes $\tau_\chi \lesssim 10^{27}$ s across leptonic channels
- Solar halo measurement provides competitive limits for GeV – TeV masses
- Surpasses galactic γ-ray constraints at intermediate mass window
- Leading local probe above a TeV where AMS-02 loses sensitivity

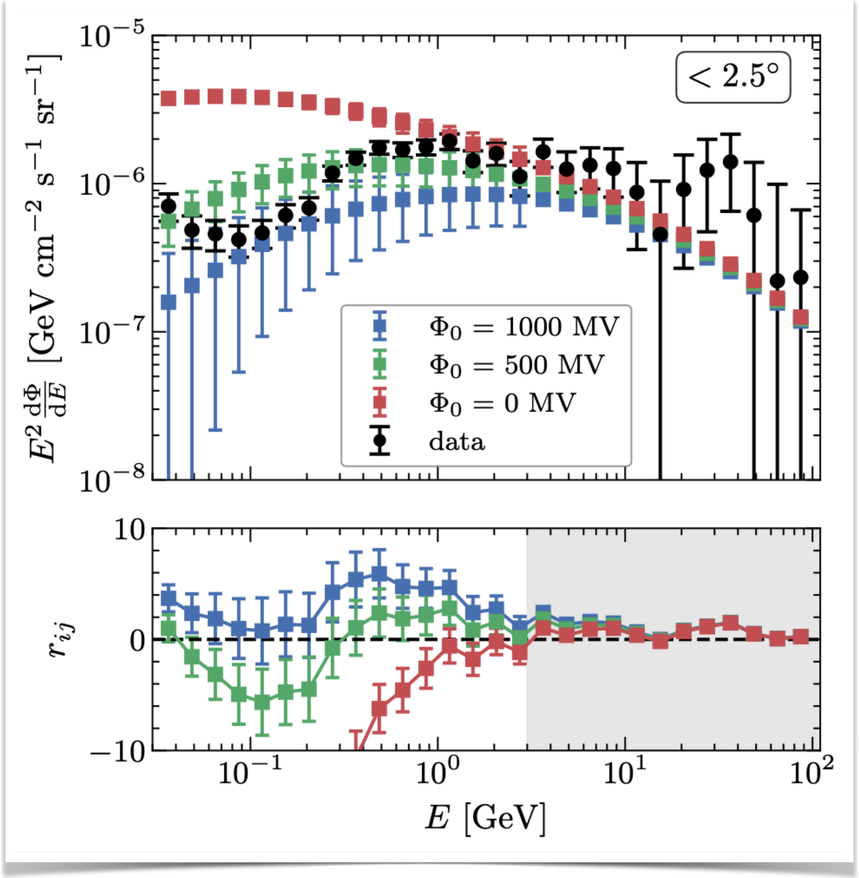
Conclusions

- The Sun acts as a local IC converter: DM-decay $e^{\pm}$ up-scatter solar photons into an extended γ ray halo
- First quantitative use of the solar ICS halo as an indirect probe of decaying DM
- 15 years of Fermi-LAT data constrain leptonic decay channels to $\tau_\chi \gtrsim 10^{27}$ s for $m_\chi \sim 10\,\mathrm{GeV} - 10\,\mathrm{TeV}$
- Surpasses Galactic diffuse constraints in an intermediate-mass window: a genuinely independent channel with different systematics
- Leading above ~ 1 TeV, where AMS-02 $e^{\pm}$ measurement loses sensitivity

Thank you

Backup slides

Statistics



Gaussian likelihood with
DM-induced signal component
and background from interstellar $e^{\pm}$ spectrum

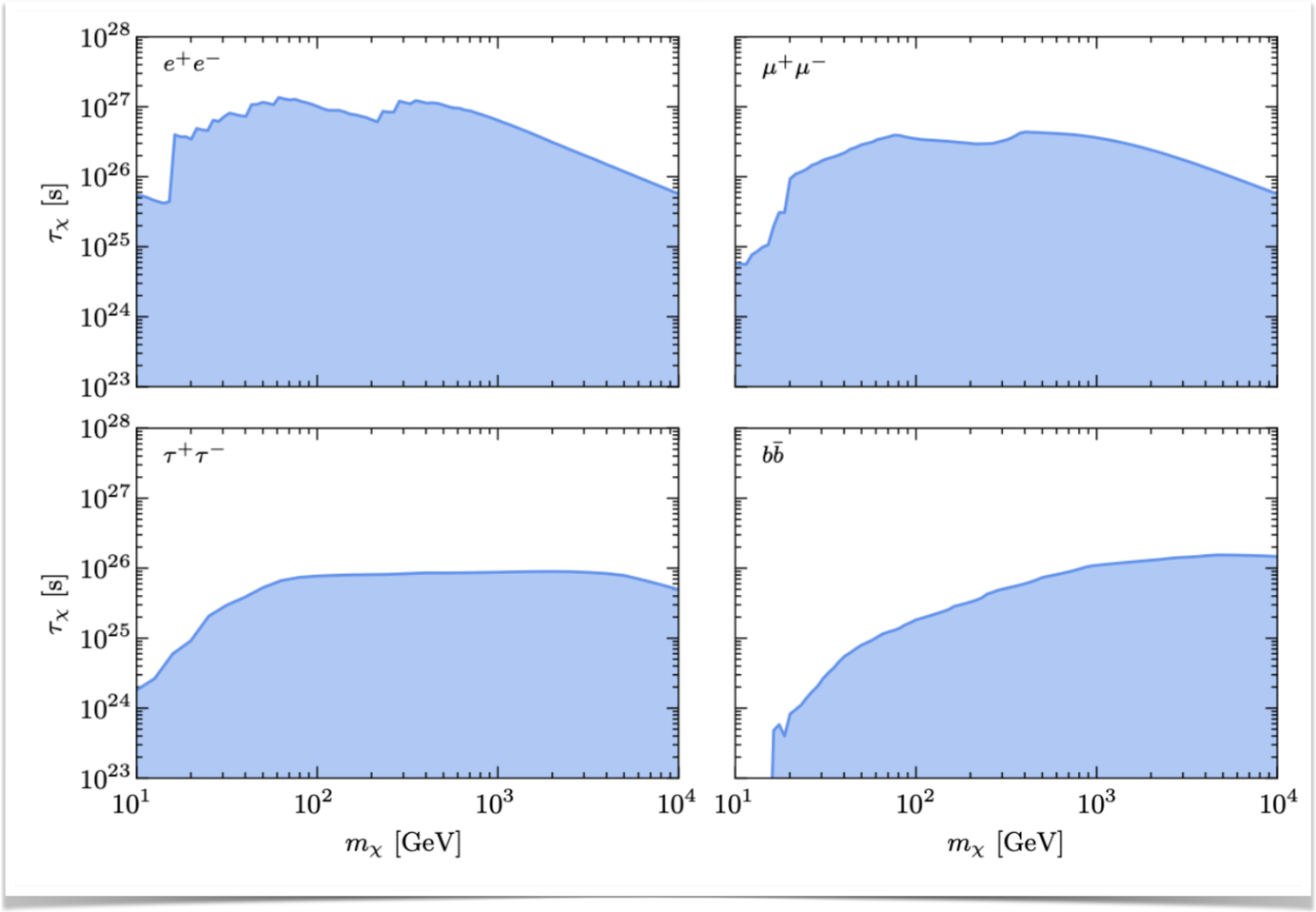
$$\ell(\tau_\chi, m_\chi, \boldsymbol{\theta}) = -\frac{1}{2} \sum_{i,j} \frac{(d_{ij} - s_{ij}(\tau_\chi, m_\chi, \boldsymbol{\theta}) - b_{ij}(\boldsymbol{\theta}))^2}{\sigma^2_{ij,\mathrm{tot}}}$$

Conservative treatment: introduce systematic error for background mismodelling

$$\sigma^2_{ij,\mathrm{tot}} = \sigma^2_{ij} + (\sigma^{\mathrm{sys}}_{ij})^2 = \sigma^2_{ij} + (\epsilon_{\mathrm{sys}} \cdot b_{ij}(\boldsymbol{\theta}))^2$$

Other decay channels

Light decay channels



Other decay channels

Heavy decay channels