Co-SIMP Miracle

Juri Smirnov

CCAPP

Newton 1665: 06/29/20

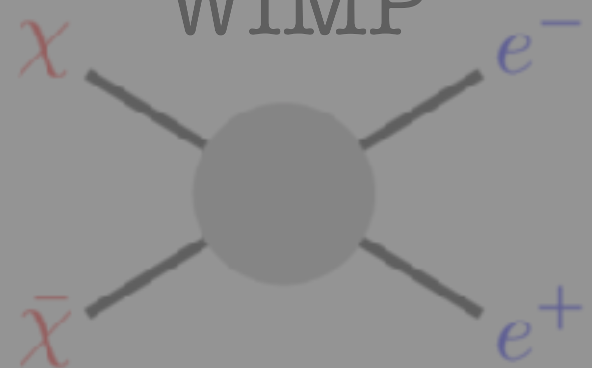
In collaboration with: John Beacom (OSU, CCAPP)

The Ohio State University

Production

Freezeouts

WIMP

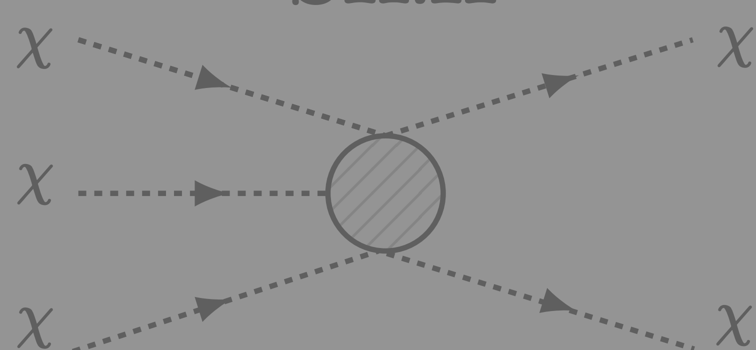


Zeldovich, Lee, Weinberg, Steigman, Turner,...

$$\Gamma_{\rm DM} = \langle \sigma v_{\rm rel.} \rangle \, n_{\rm DM} > H(T)$$

$$\Omega_{\rm DM} \, h^2 \approx \frac{0.12}{\langle \sigma v_{\rm rel.} \rangle \, [25 \mathrm{TeV}]^2}$$

SIMP

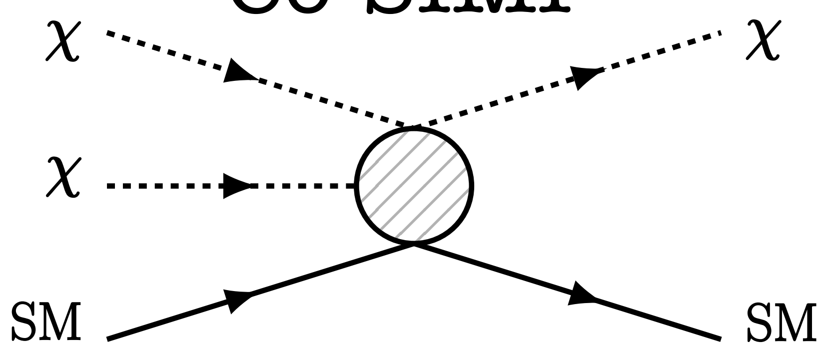


Hochberg, Kuflik, Volansky, Wacker

$$\Gamma_{\rm DM} = \langle \sigma_{3\to 2} v^2_{\rm rel.} \rangle \, n^2_{\rm DM} > H(T)$$

$$\Omega_{\rm DM} \, h^2 \approx \left(\frac{\mathrm{MeV}}{m_{\rm DM}} \right) \frac{0.12}{\sqrt{\langle \sigma_{3\to 2} v^2_{\rm rel.} \rangle \, [3 \mathrm{MeV}]^5}}$$

Co-SIMP

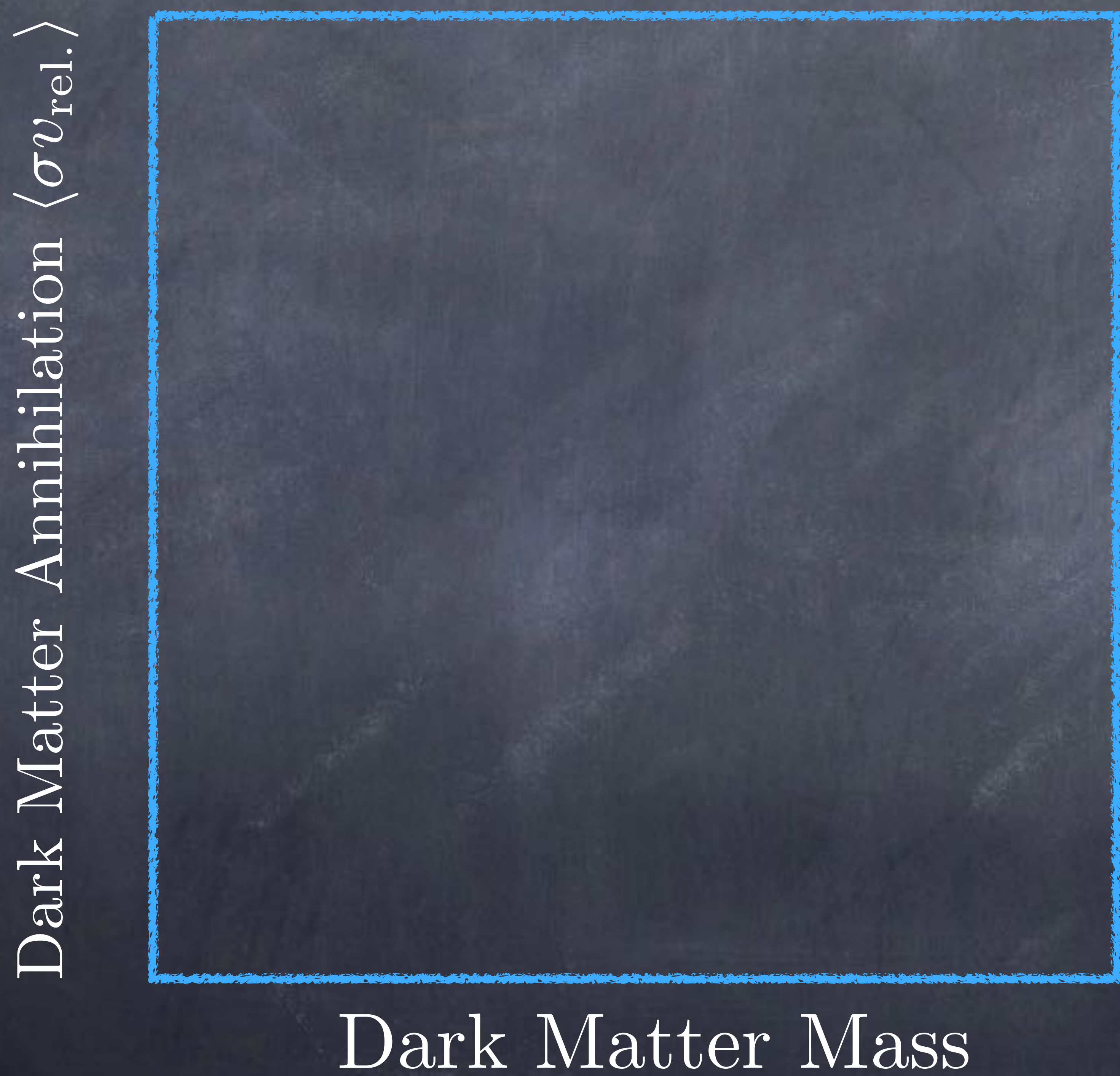


Smirnov, Beacom

$$\Gamma_{\rm DM} = \langle \sigma_{3\to 2} v^2_{\rm rel.} \rangle \, n_{\rm DM} n_{\rm SM} > H(T)$$

$$\Omega_{\rm DM} h^2 \approx \left(\frac{\mathrm{MeV}}{m_{DM}} \right)^3 \frac{0.12}{\langle \sigma_{3\to 2} v^2_{\rm rel.} \rangle [100 \, \mathrm{MeV}]^5}$$

Cartoon Overview of Approach



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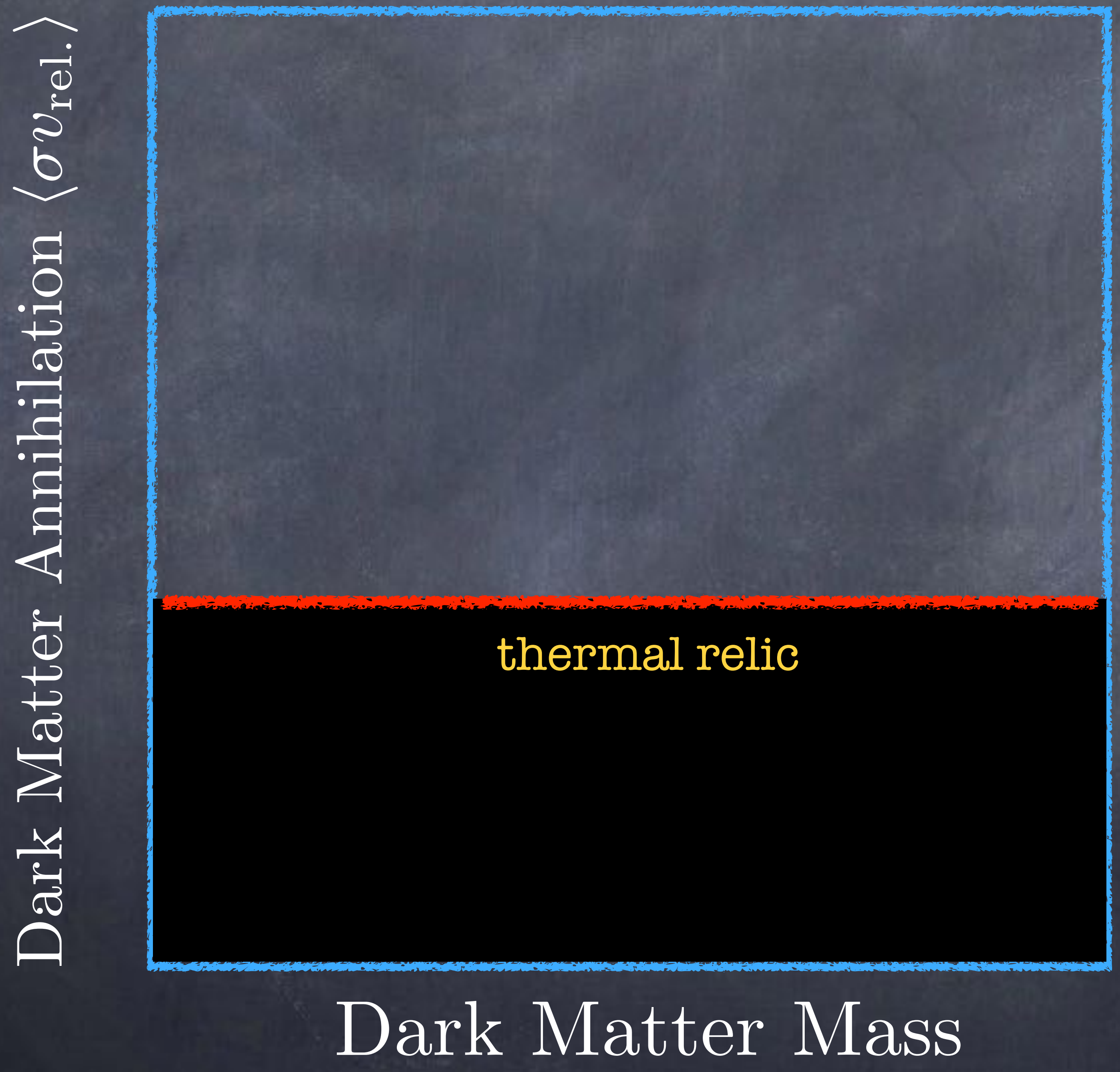

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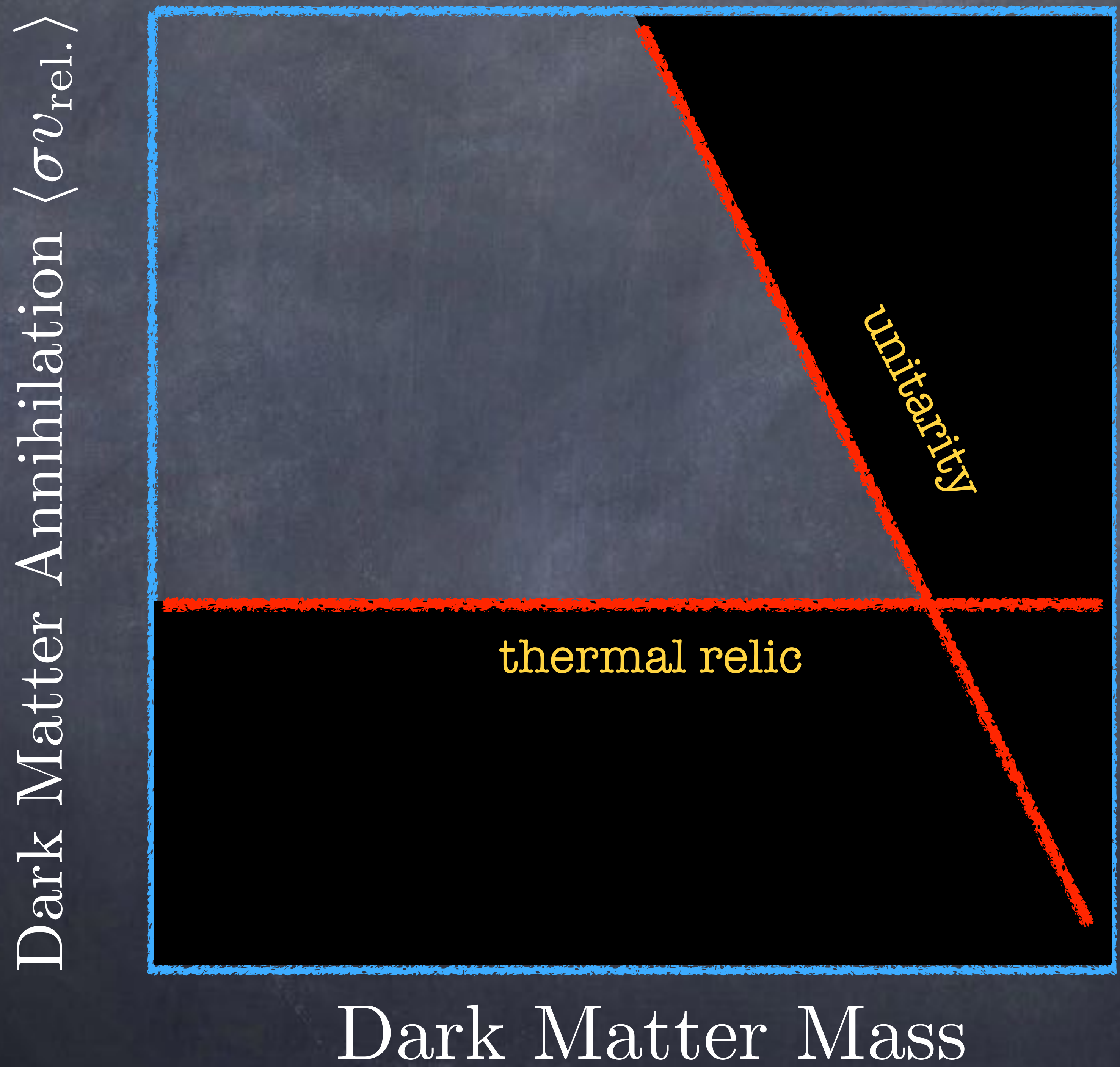

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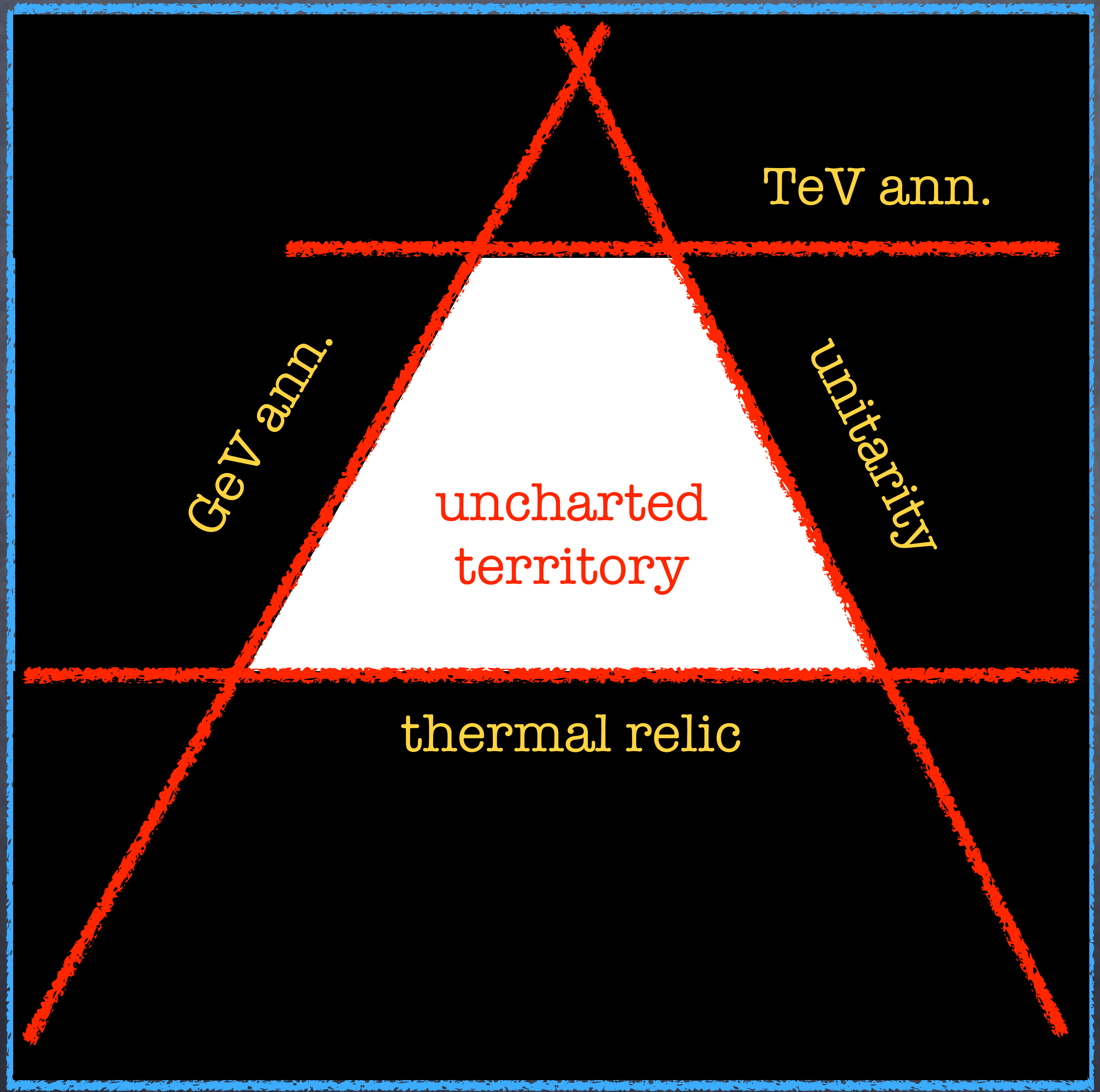
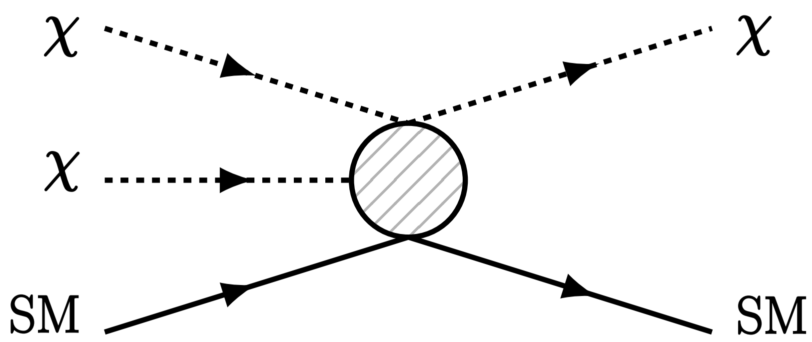


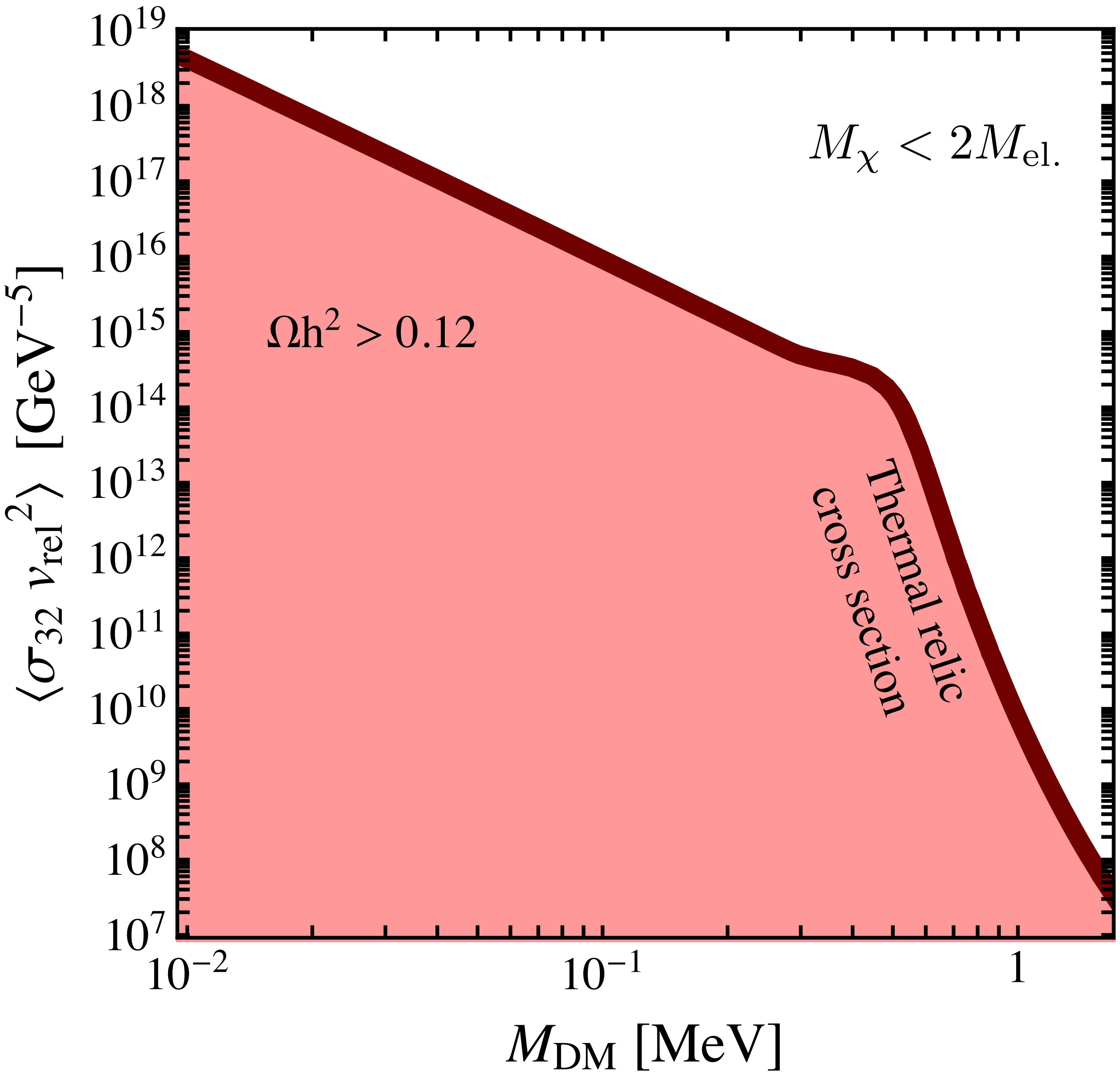
Dark Matter Mass

Dark Matter Annihilation $\langle \sigma v_{\rm rel.} \rangle$

Co-SIMP Parameter Space



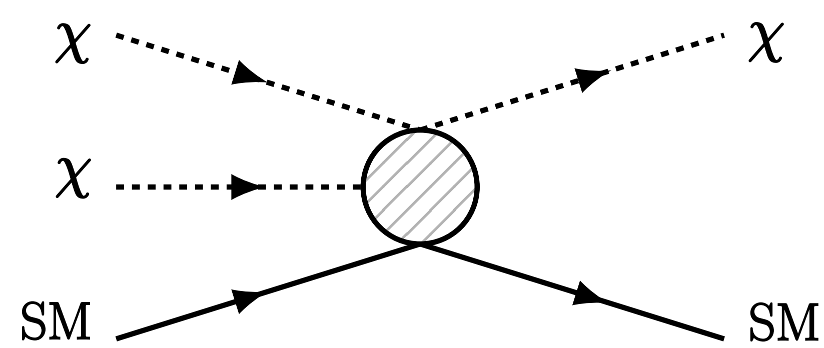
$$M_\chi < 2M_{\rm SM}$$

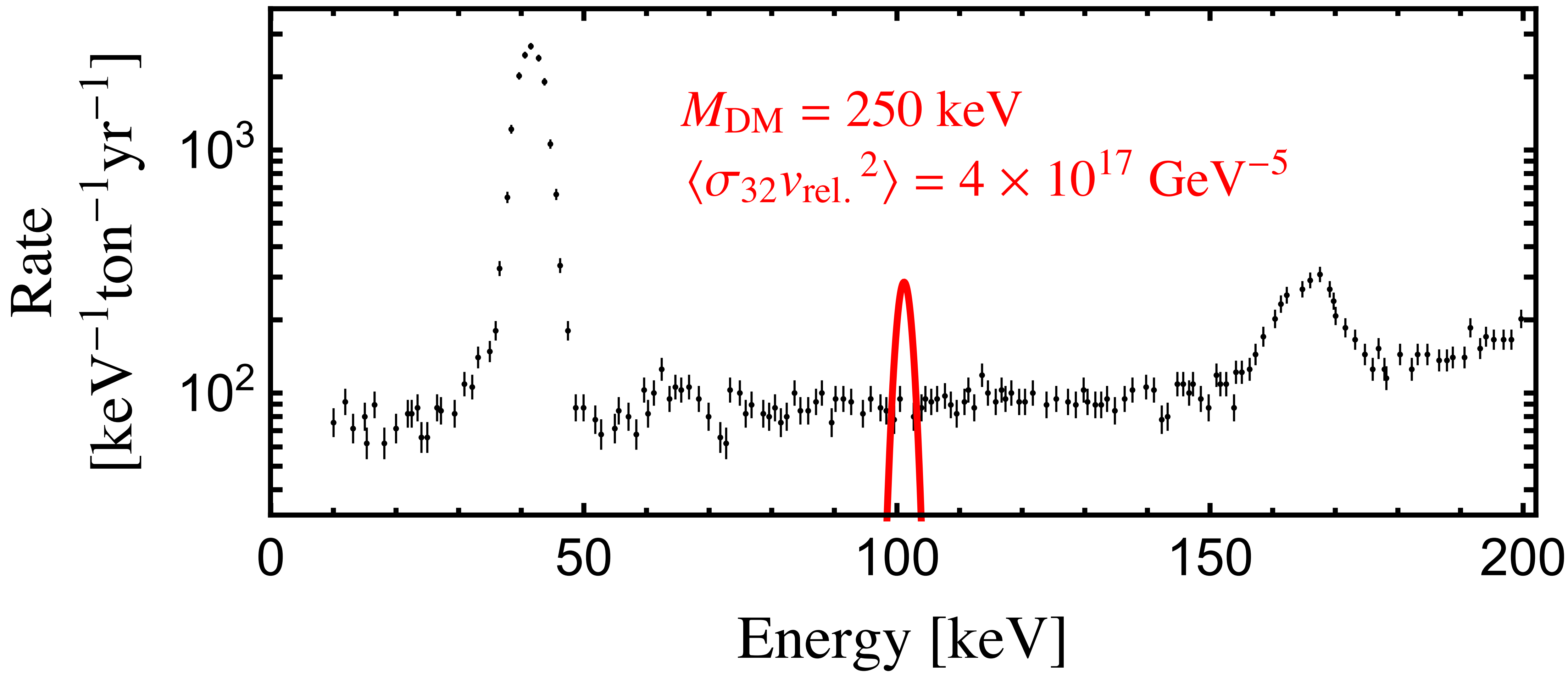


arXiv: 2002.04038; J. Smirnov, J. Beacom

Electrophilic Co-SIMP

Monoenergetic Recoil





arXiv: 2002.04038; J. Smirnov, J. Beacom

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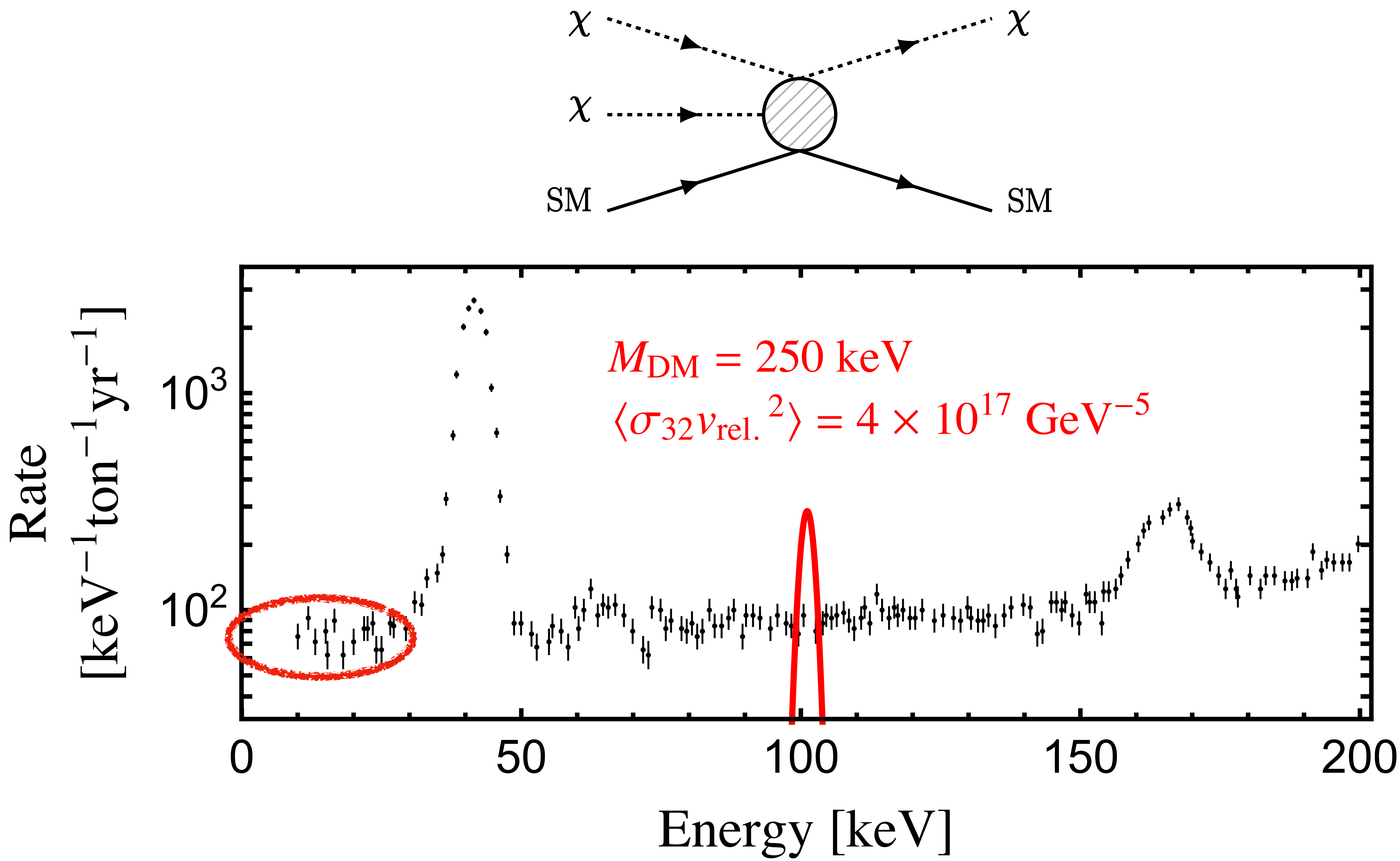

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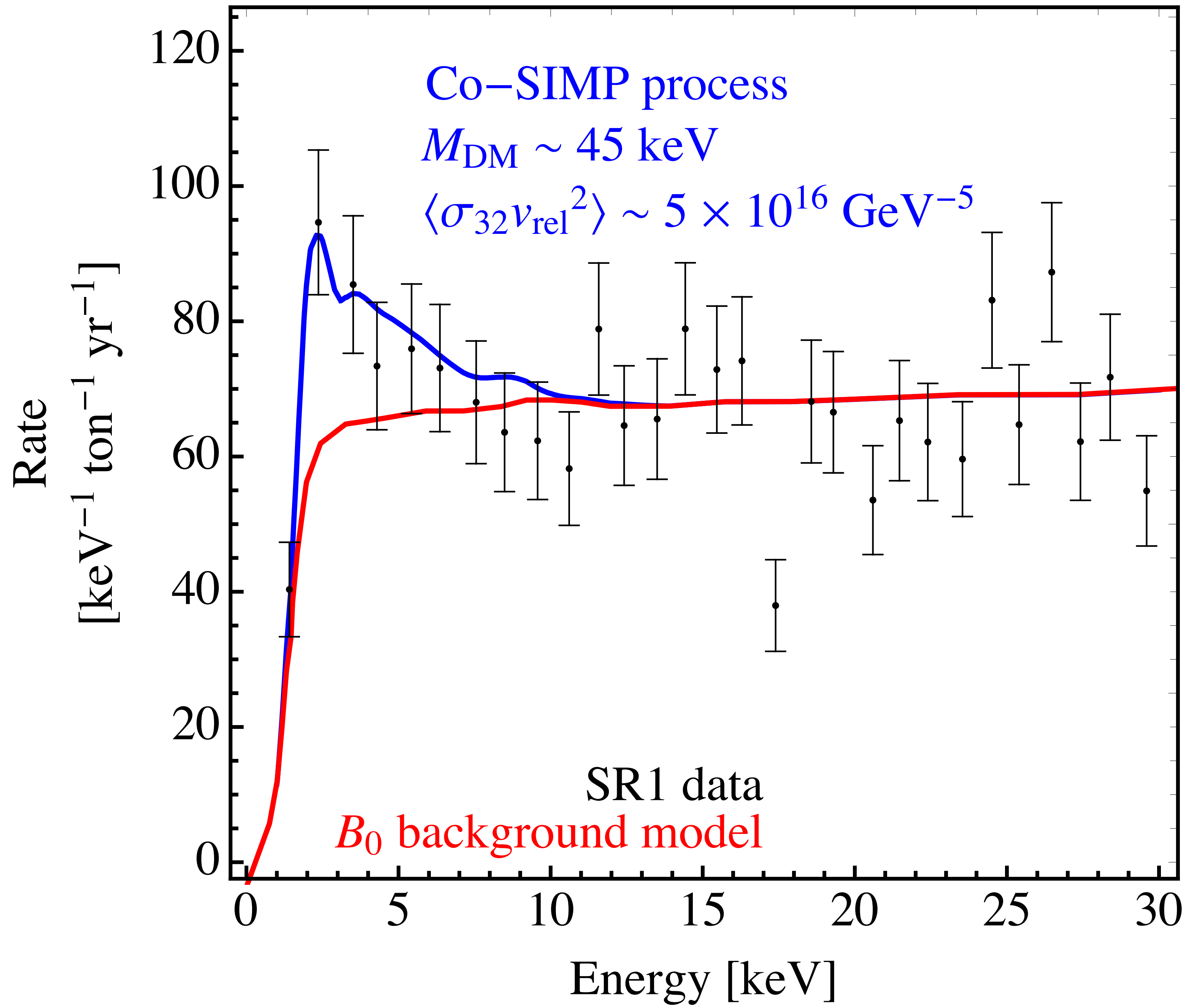
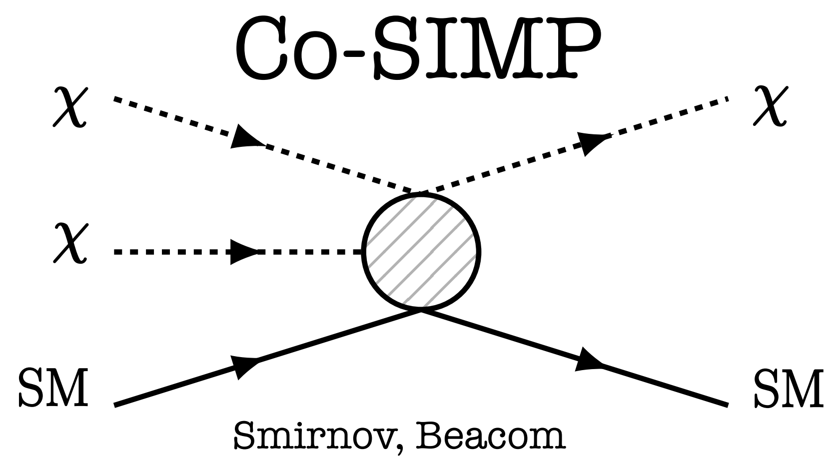
XENON1T Signal



v2 on arXiv today: arXiv: 2002.04038v2; J. Smirnov, J. Beacom

Look right here effect



$$\Gamma_{\rm DM} = \langle \sigma_{3\to 2} v^2_{\rm rel.} \rangle\, n_{\rm DM} n_{\rm SM} > H(T)$$

$$\Omega_{\rm DM} h^2 \approx \left(\frac{\rm MeV}{m_{DM}}\right)^3 \frac{0.12}{\langle \sigma_{3\to 2} v^2_{\rm rel.}\rangle [100\,{\rm MeV}]^5}$$

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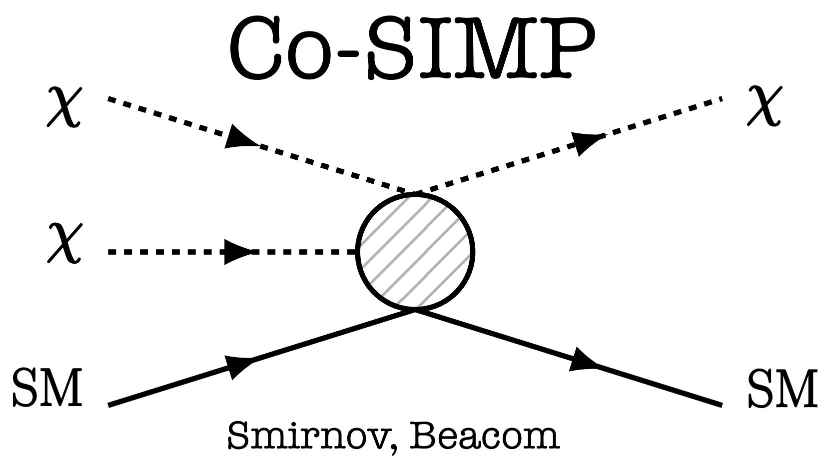

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Given XENON1T mass and exposure:

$$+50 \text{ events} \Rightarrow M_{\rm DM} \approx 30 - 50 \text{ keV}$$

$$\Rightarrow E_R \approx 2 - 6 \text{ keV}$$

Juri Smirnov, smirnov.9@osu.edu, CCAPP @ OSU; Newton, 29/16/20

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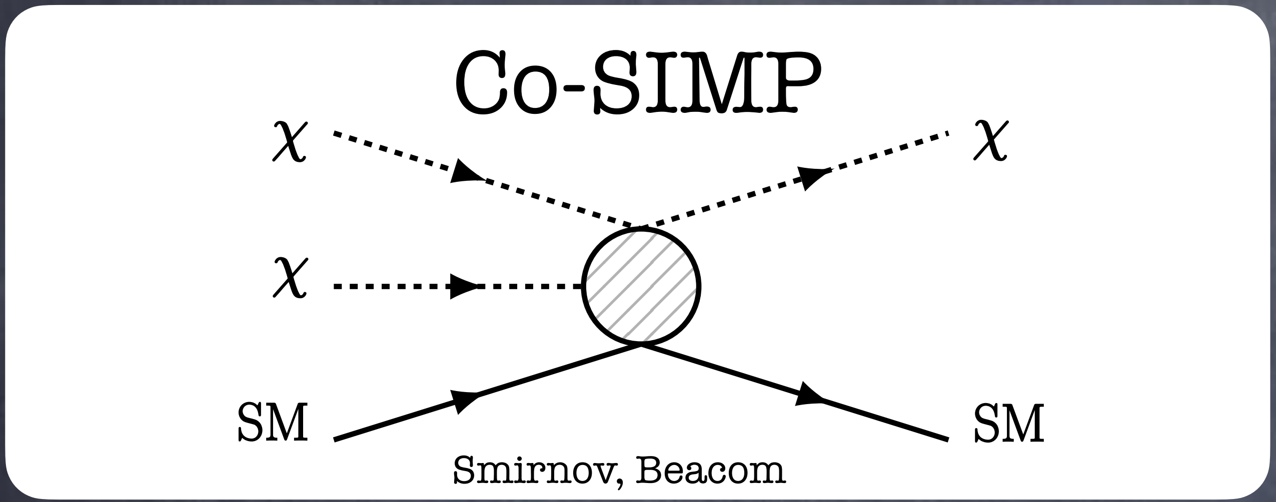

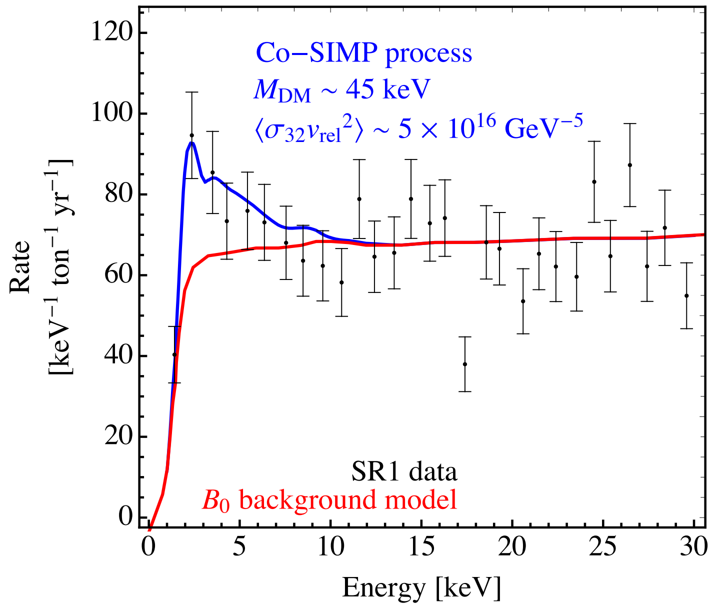

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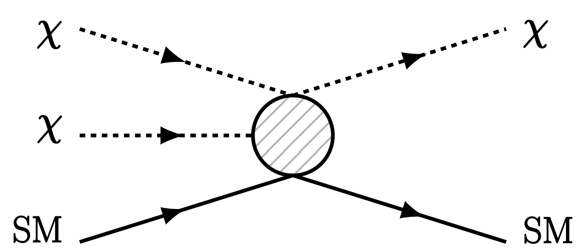
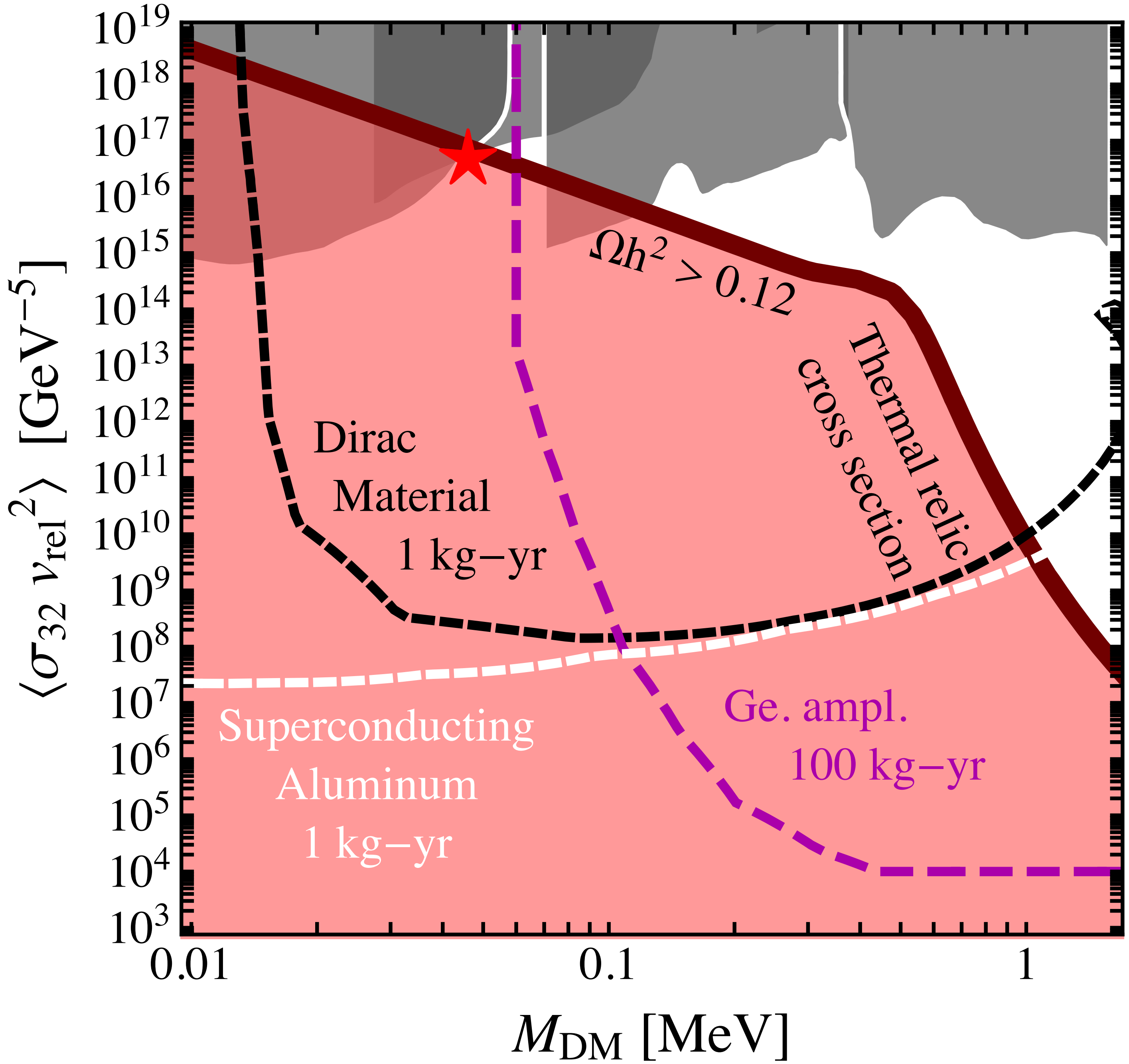
Implications

Scattering off Electrons





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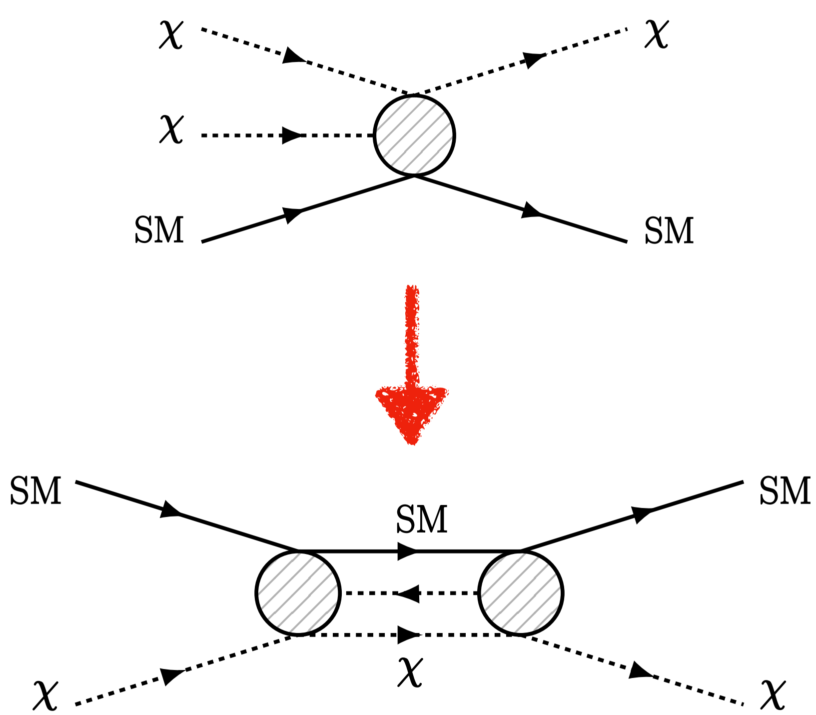

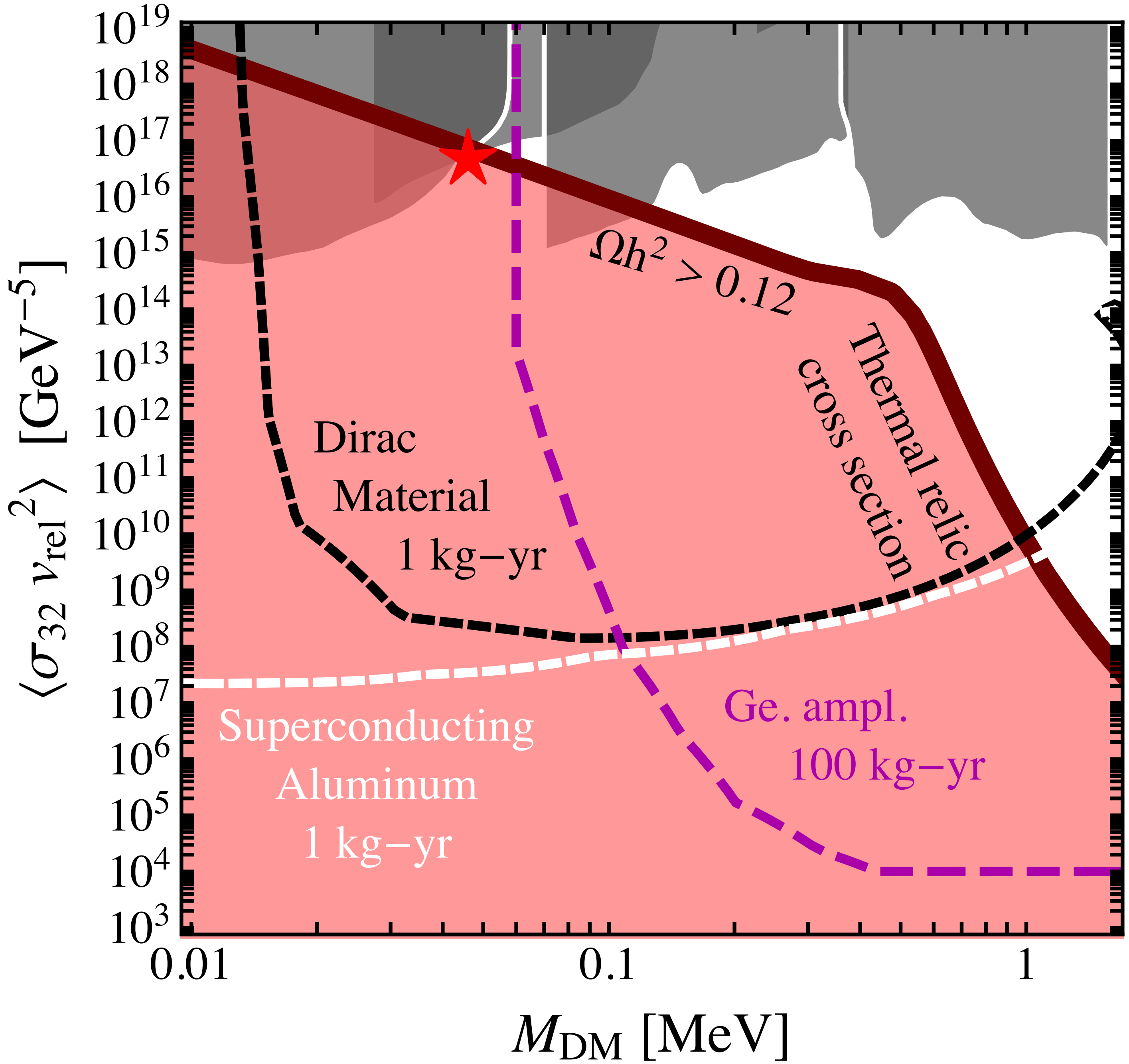

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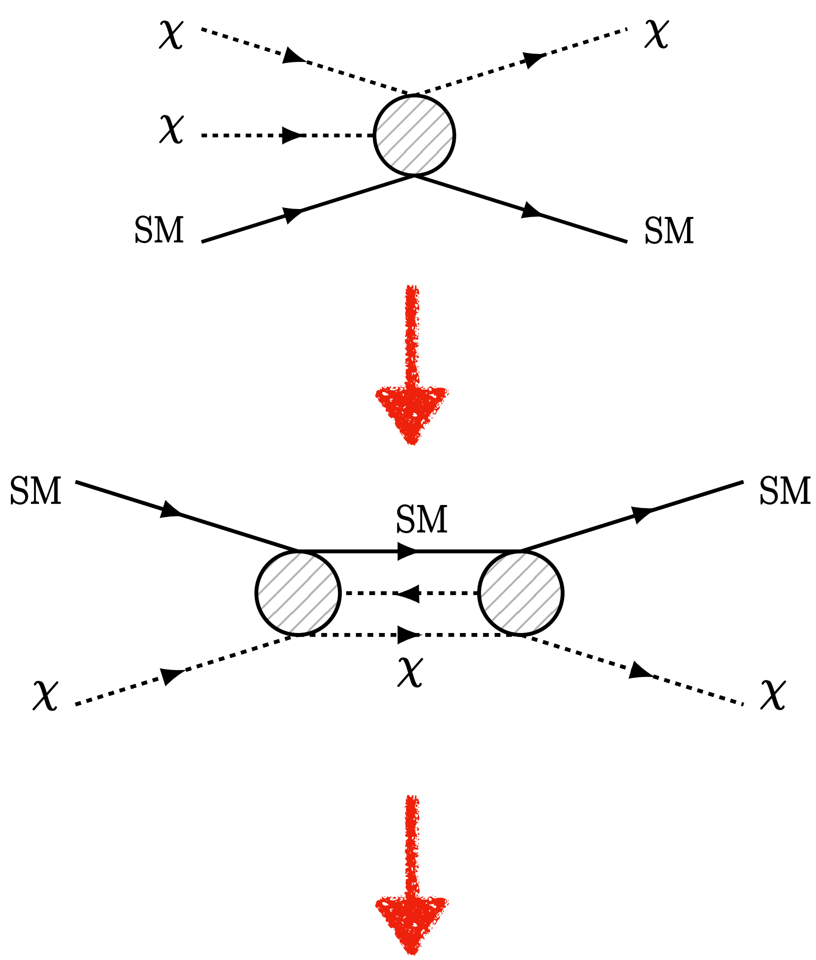
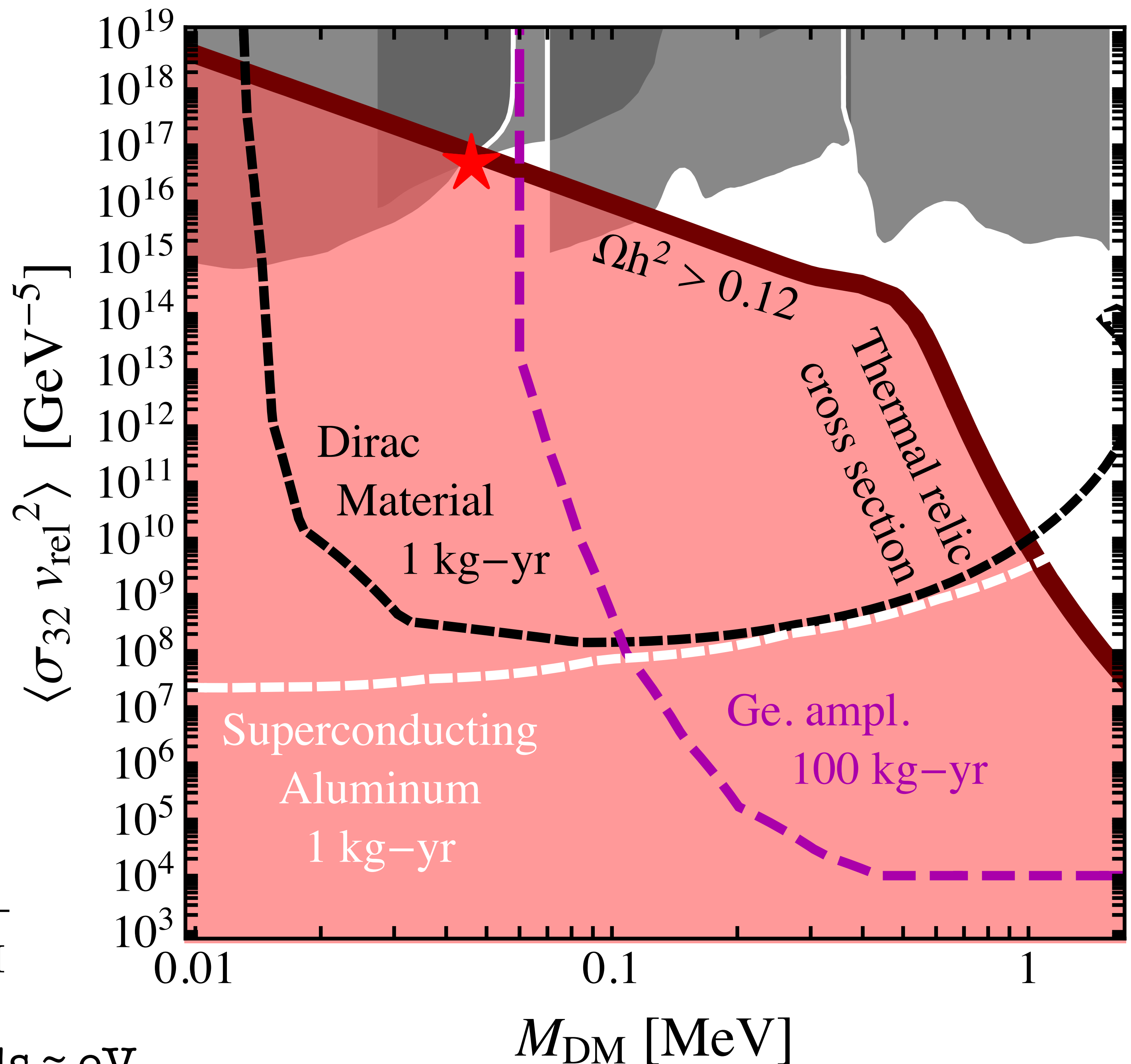


$$\sigma_{\chi e} \sim 10^{-37}\mathrm{cm}^2 \qquad E_R \approx v_{\mathrm{rel}}^2 \frac{\mu^2}{M_{\mathrm{SM}}}$$

Detectors with lower energy thresholds ≈ eV



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A. New target for low energy recoils at 30 - 50 keV

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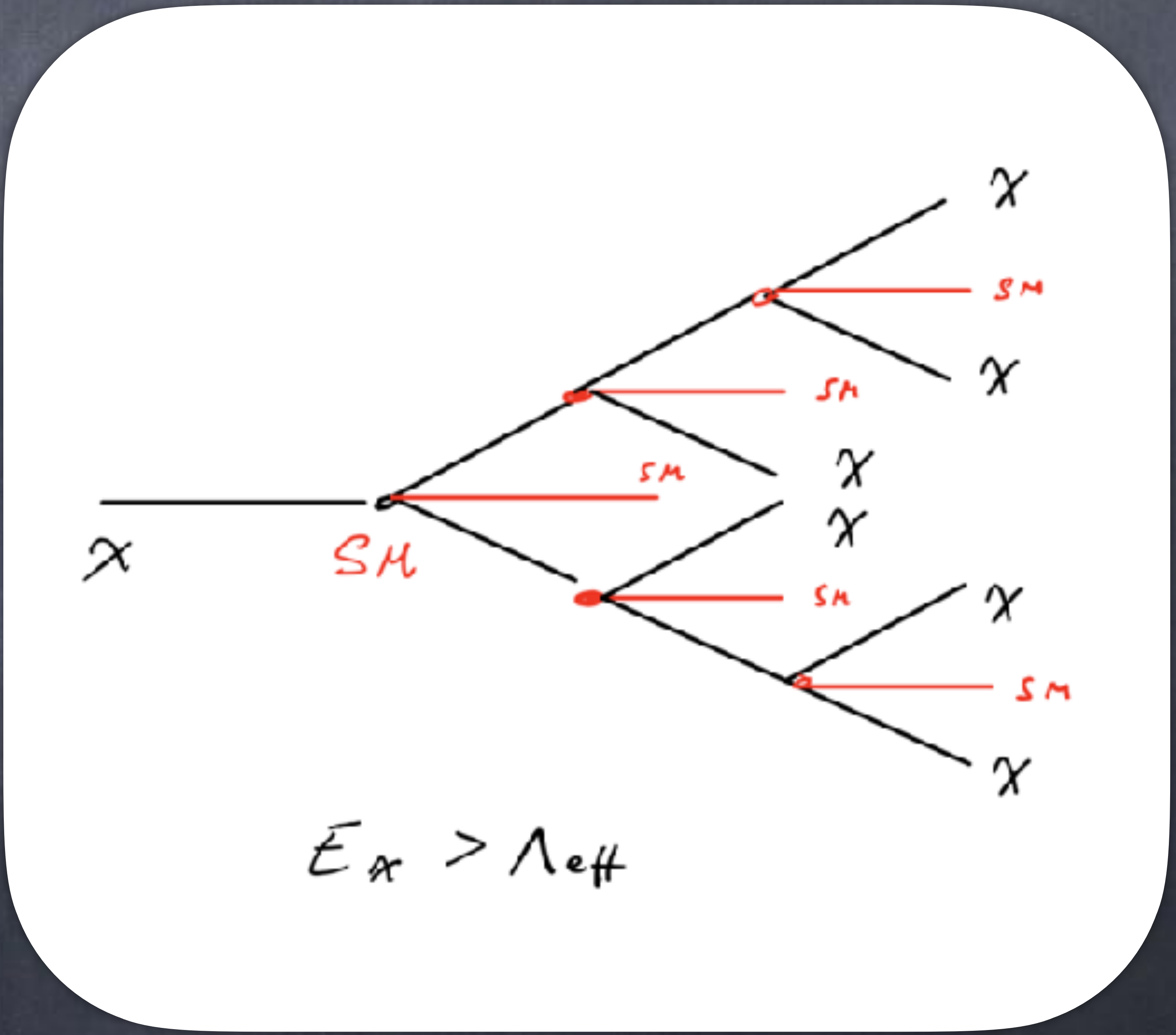
D. New collider signatures expected

Questions for UV completions



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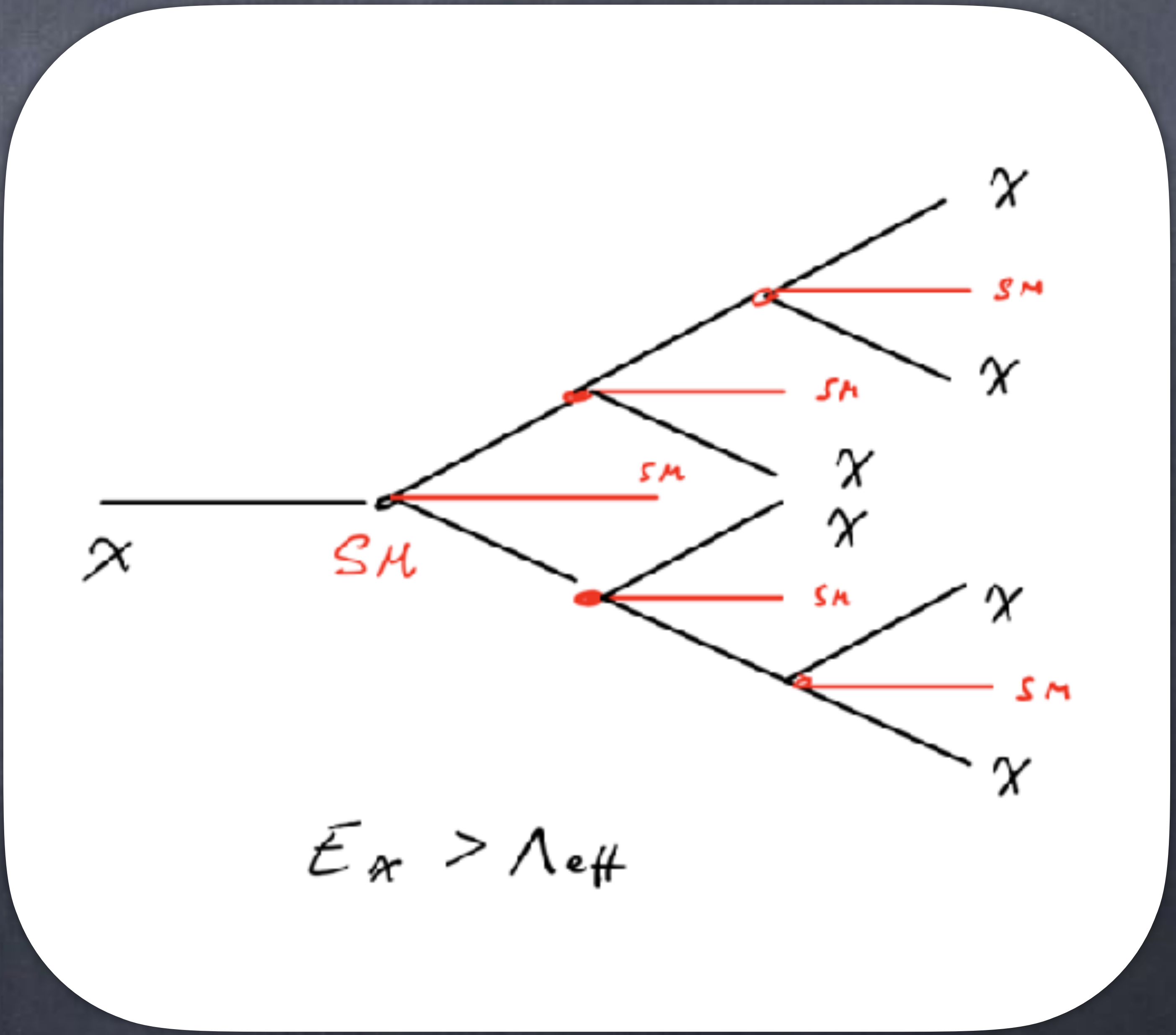
Questions for UV completions

A. Emerging Showers?

Hadronic and

Electromagnetic



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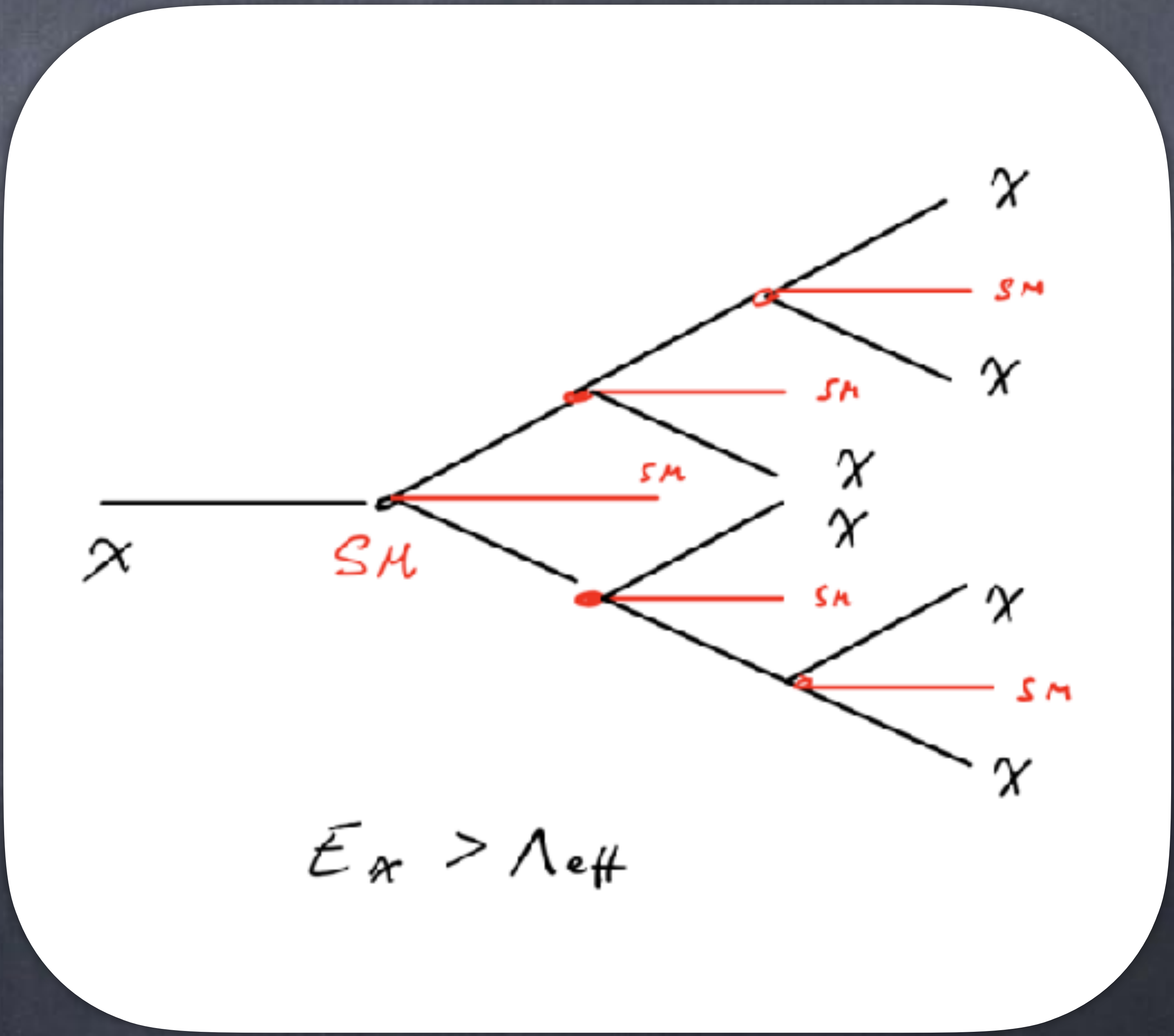
B. Opacity of materials



Questions for UV completions

A. Emerging Showers?

Hadronic and

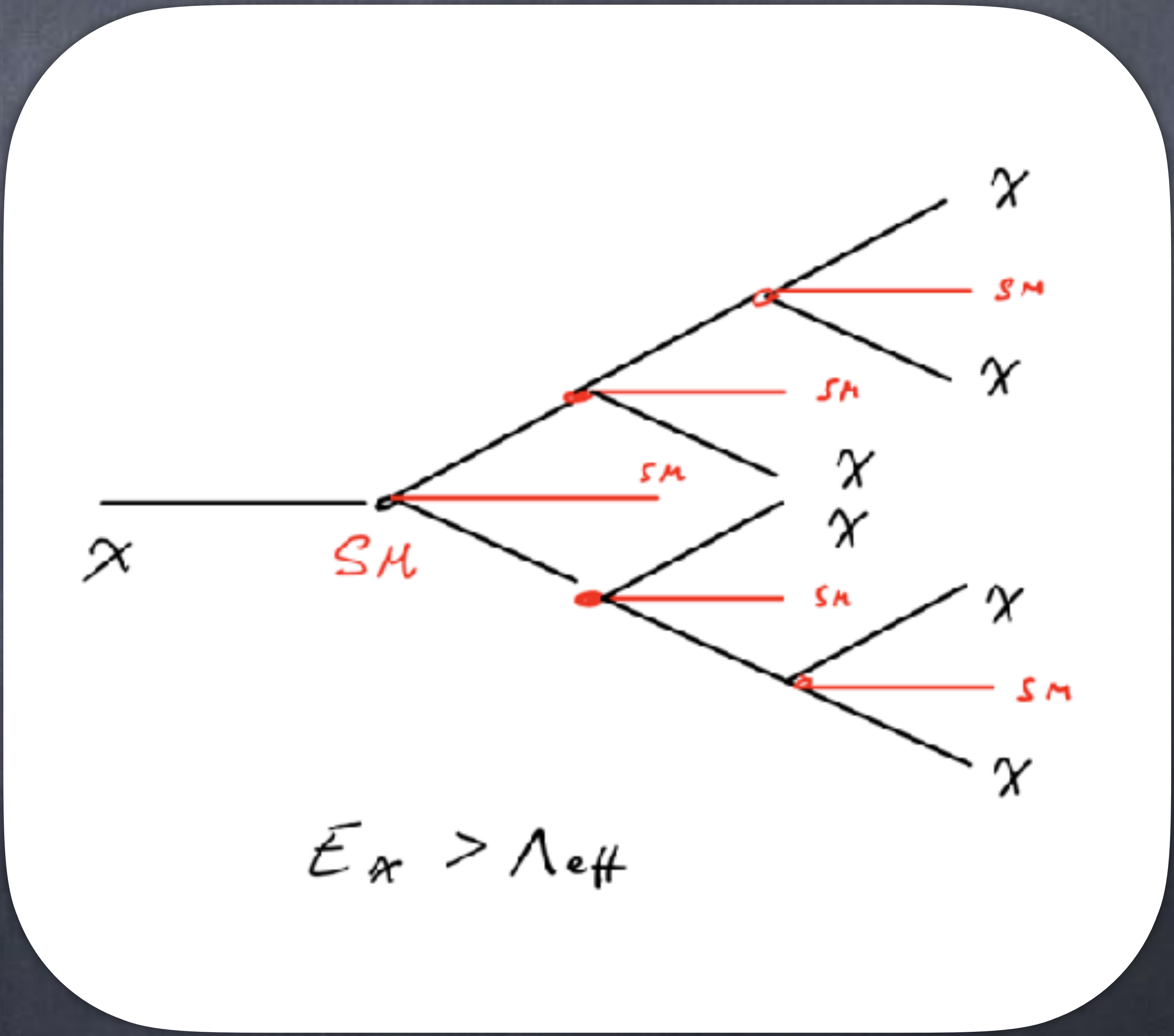
Electromagnetic

B. Opacity of materials

C. Loop coefficients

-> Work in progress with:

Bei Zhou and John Beacom



Summary

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A. New thermal Dark Matter production

mechanism proposed

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B. The fundamental process can be directly tested in lab and consistent with XENON1T excess

C. Can be confirmed with low threshold detectors, new astrophysical probes, ...

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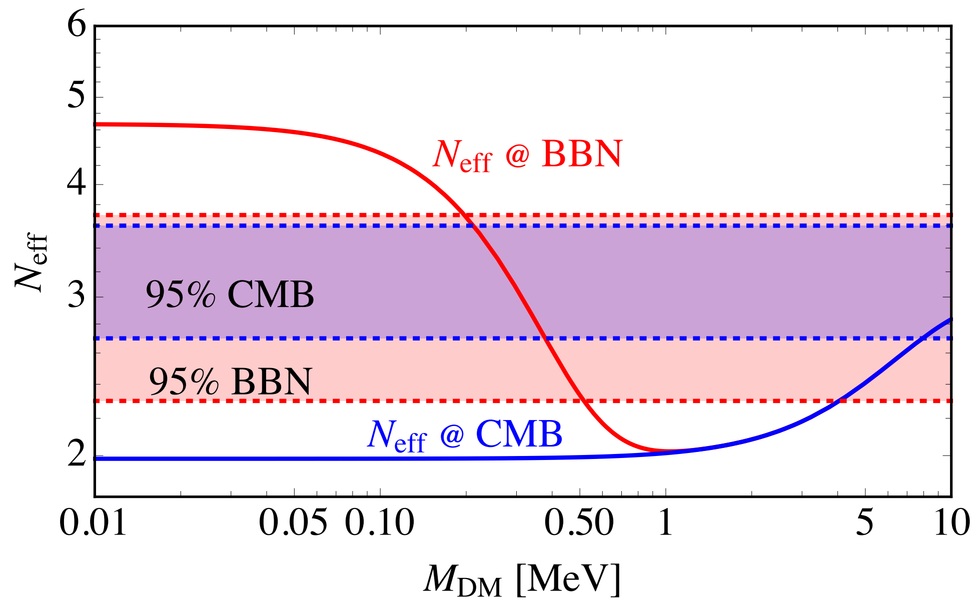
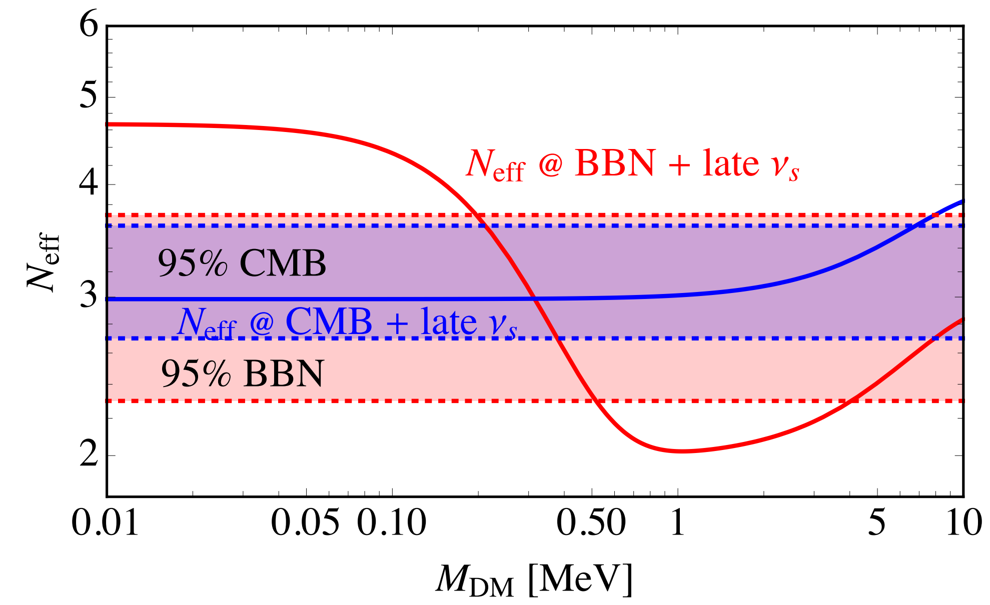
Thanks!

Neff for coupling to Electrons

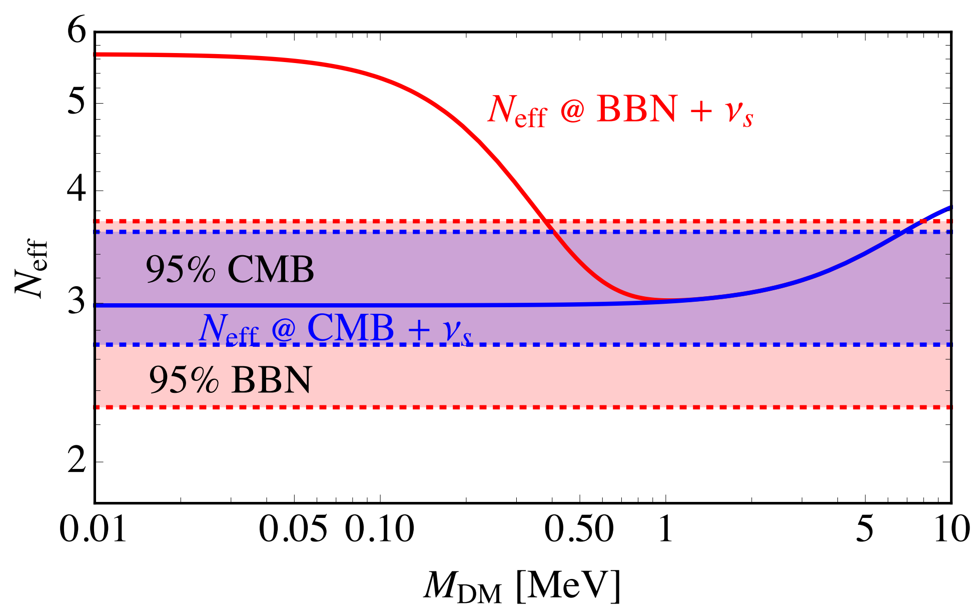
Lonely Co-SIMP



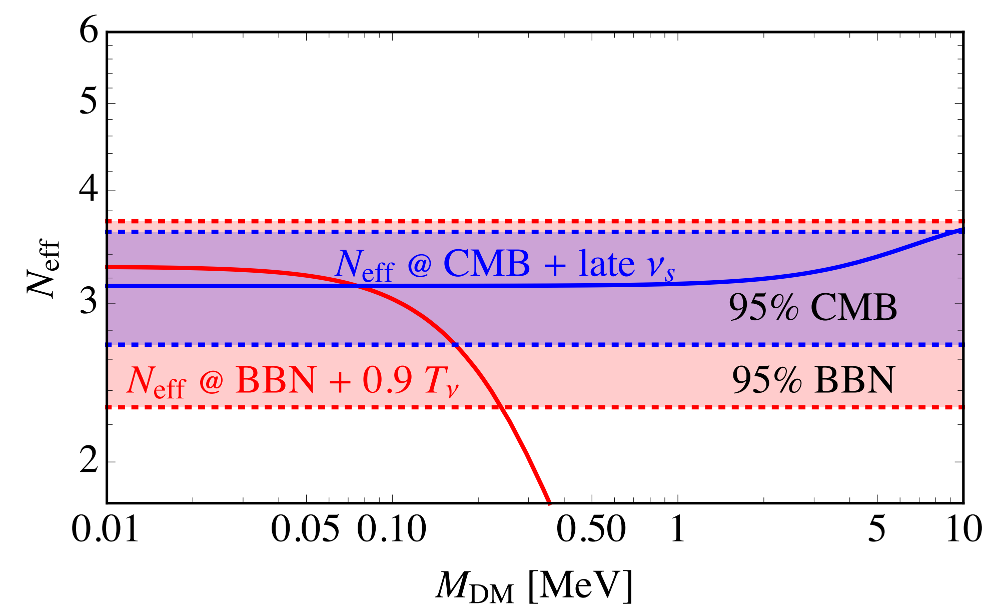
Co-SIMP + late sterile Nu



Co-SIMP + sterile Nu



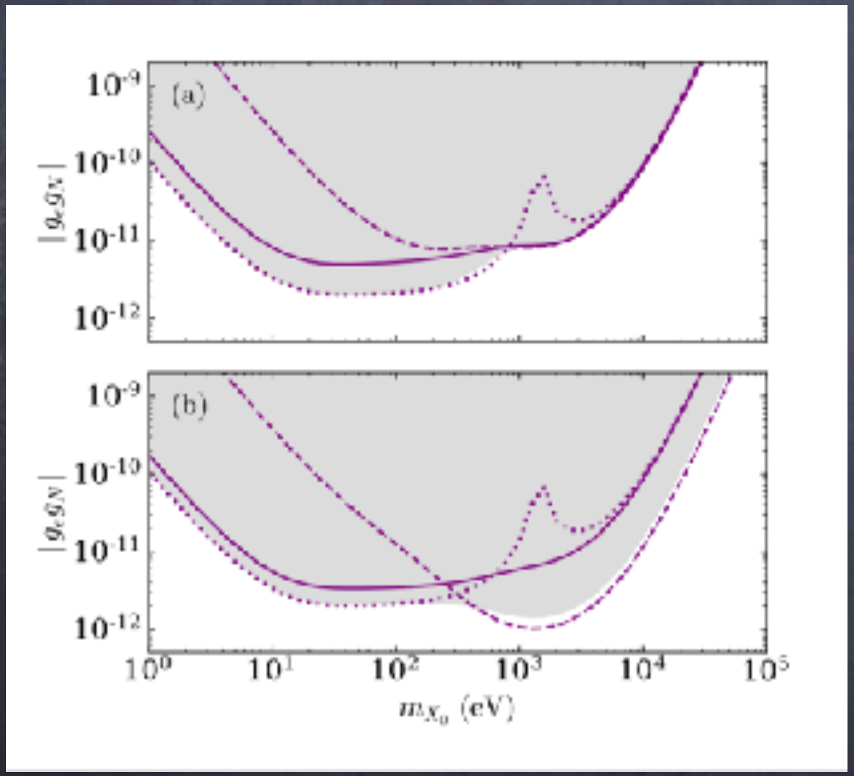
Co-SIMP + low Tv



New Forces

Long Range: light Z’

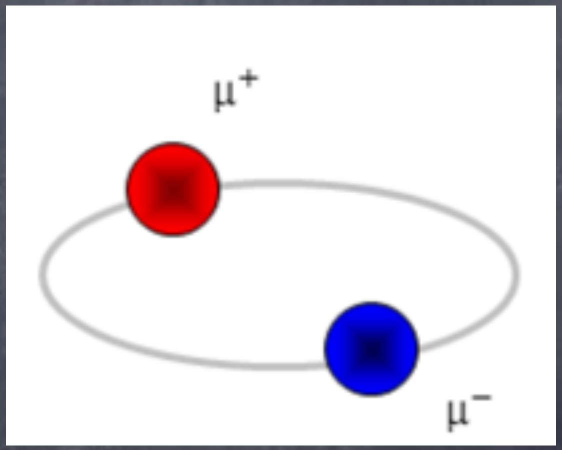
Rydberg Atoms (n>>1):



arXiv: Jones, Potviliege, Spannowsky

Short Range: loops, heavy Z’

Need compactness:
True Muonium



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JCAP 1404 (2014) 022:

Kopp, Michaels, JS

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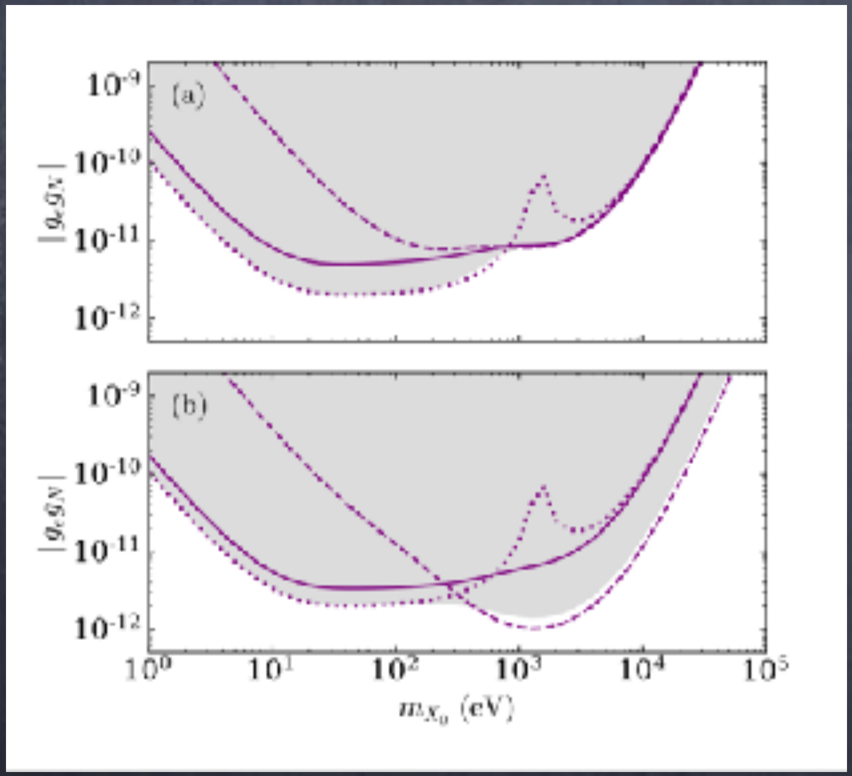

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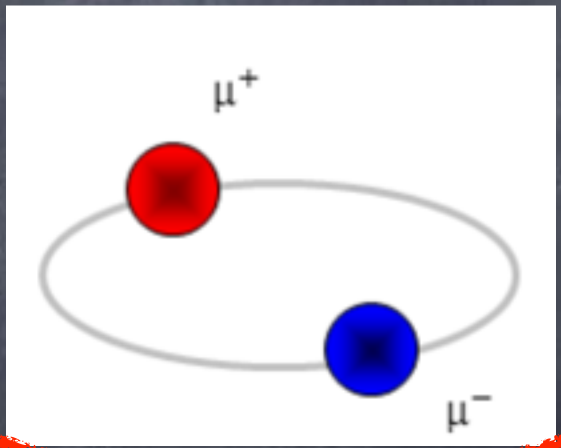

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Positronium

$$\Delta E_{\mathrm{hfs}} \approx -\frac{\alpha_{\mathrm{EM}}^3 m_\ell^3}{8\pi}\frac{1}{128\pi^4\,\Lambda^2}$$

JCAP 1404 (2014) 022:

Kopp, Michaels, JS

$$\Delta E_{\mathrm{hfs}}^{e^+e^-} \approx -43\ \mathrm{Hz} \times \left(\frac{\mathrm{GeV}}{\Lambda}\right)^2$$

$$\Delta E/E \approx \mathcal{O}(10^{-10})$$

True Muonium

$$\Delta E_{\rm hfs} \approx -\frac{\alpha_{\rm EM}^3 m_\ell^3}{8\pi} \frac{1}{128\pi^4 \Lambda^2}$$

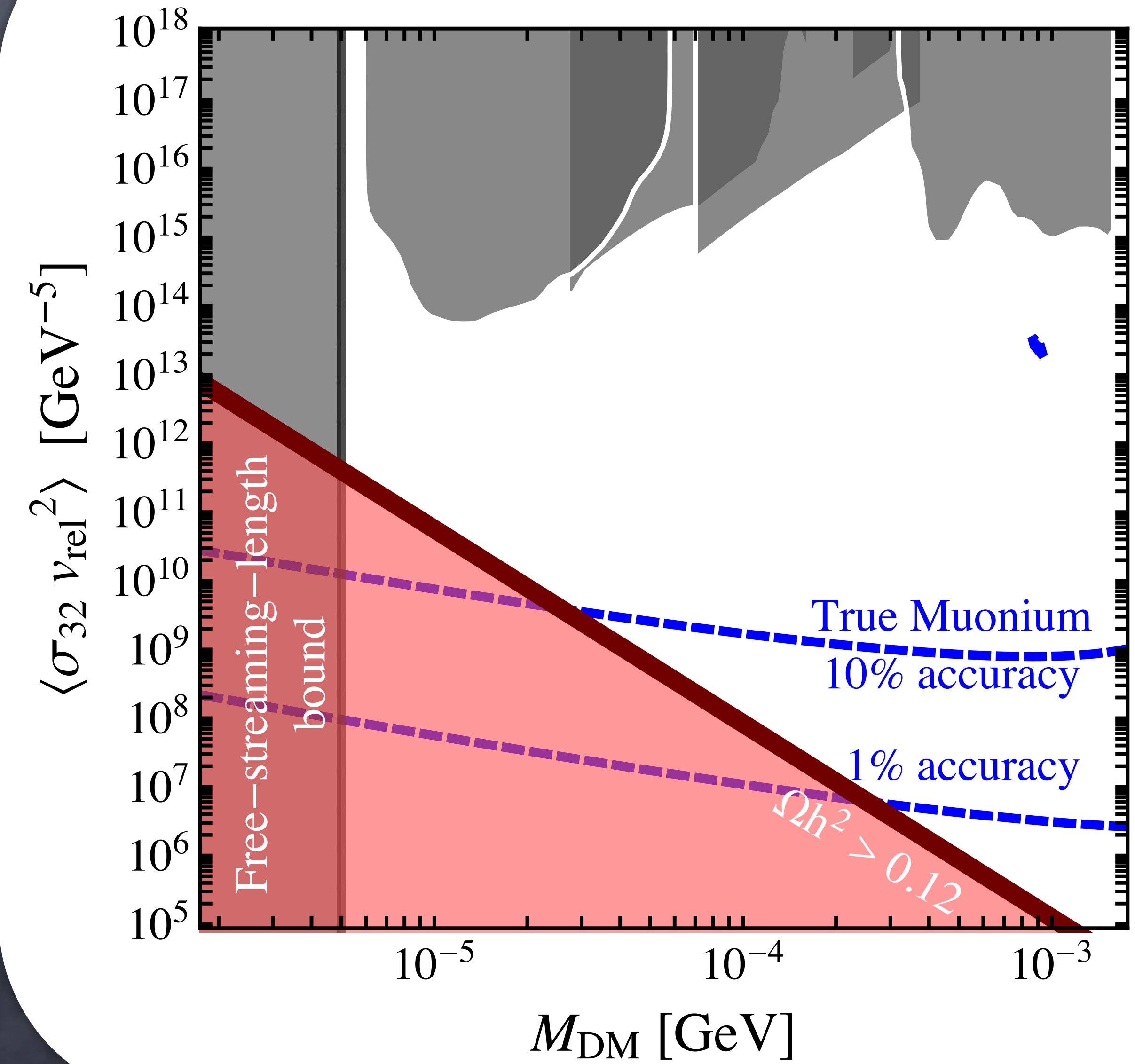
JCAP 1404 (2014) 022:
Kopp, Michaels, JS

$$\Delta E_{\rm hfs}^{e^+e^-} \approx -43 \text{ Hz} \times \left(\frac{\rm GeV}{\Lambda}\right)^2$$

$$\Delta E/E \approx \mathcal{O}(10^{-10})$$

$$\Delta E_{\rm hfs}^{\mu^+\mu^-} \approx -380 \text{ MHz} \times \left(\frac{\rm GeV}{\Lambda}\right)^2$$

Phys.Rev. D100 (2019) no.5, 053003: Vidal, Ilten, Plews, Shuve, Soreq



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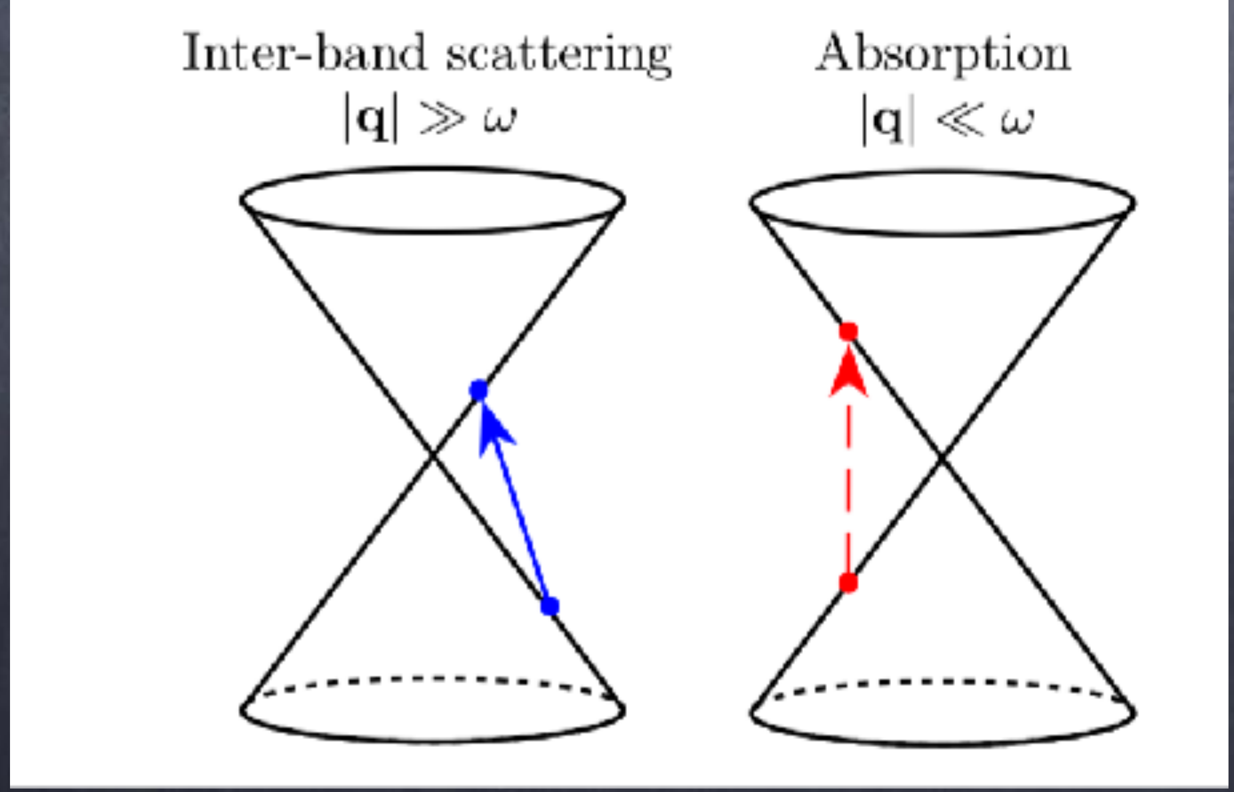
Example: Dirac Materials

$$H_{\boldsymbol{\ell}} = \begin{pmatrix} 0 & v_F \boldsymbol{\ell}\cdot\boldsymbol{\sigma} - i\Delta \\ v_F \boldsymbol{\ell}\cdot\boldsymbol{\sigma} + i\Delta & 0 \end{pmatrix}, \qquad E^{\pm}_{\boldsymbol{\ell}} = \pm\sqrt{v_F^2 \boldsymbol{\ell}^2 + \Delta^2}.$$



Neff for coupling to Electrons

$$\frac{s_\nu(T_{\mathrm{dec.}})}{s_\gamma(T_{\mathrm{dec.}})} = \frac{s_\nu(T)}{s_\gamma(T)}$$

$$\rho = \rho_\gamma \left(1 + \frac{7}{8}\left(\frac{4}{11}\right)^{4/3} N_{\mathrm{eff}}\right)$$

$$\Delta N_{eff}(T_{\mathrm{BBN}}) \approx -0.25 \text{ for } M_\chi \approx 0.2 \text{ MeV.}$$

$$\Delta N_{eff}(T_{\mathrm{BBN}}) \approx -0.5 \text{ for } M_\chi \approx 0.4 \text{ MeV.}$$

$$\Delta N_{eff}(T_{\mathrm{CMB}}) \approx -1$$

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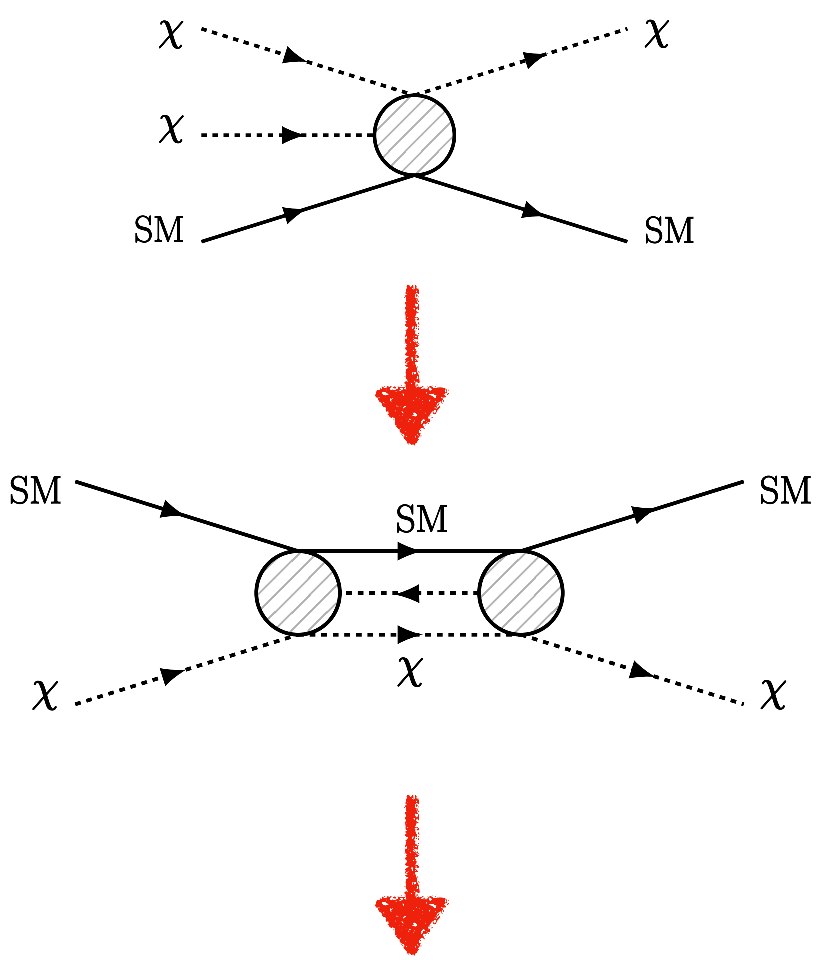
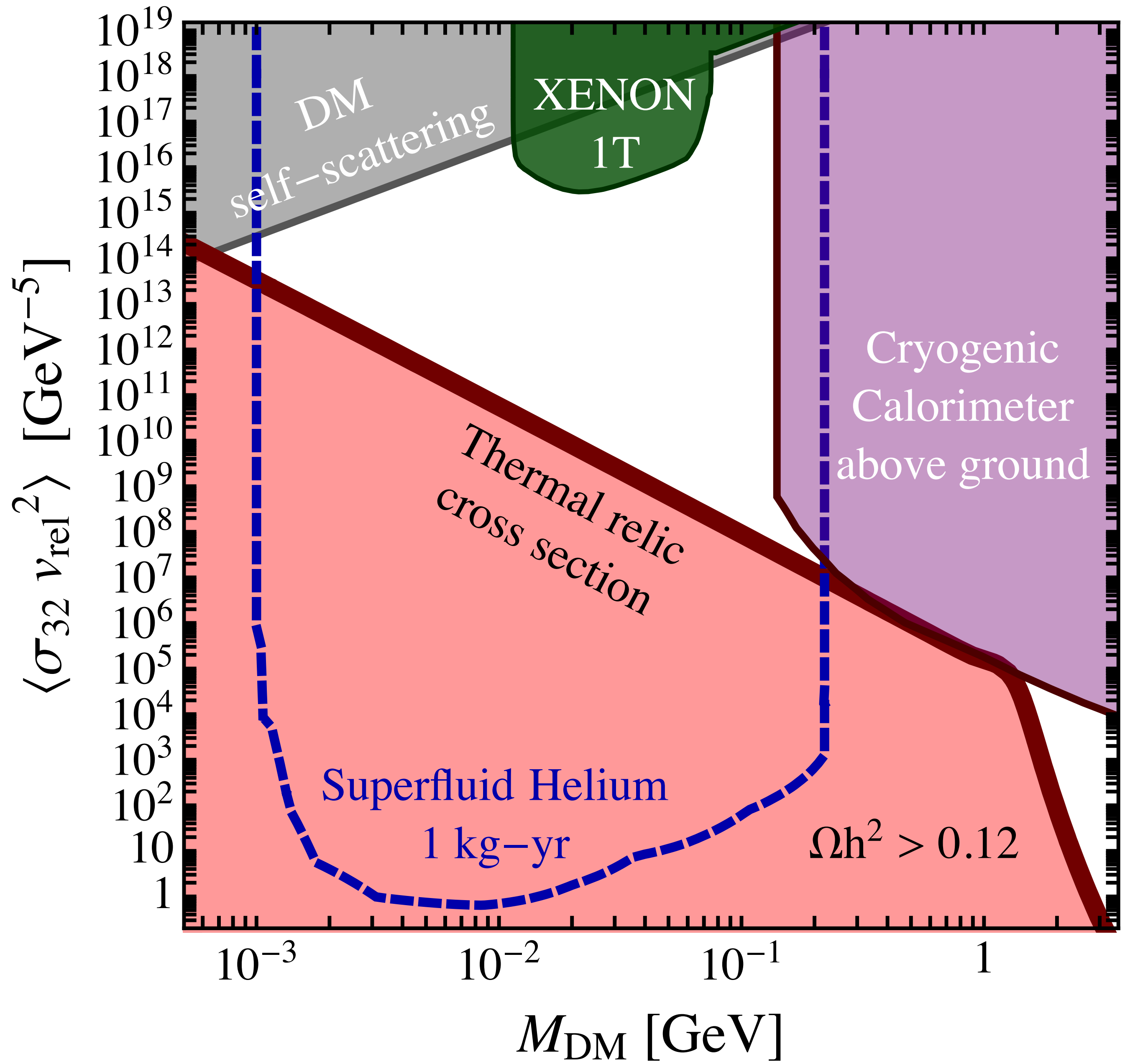
Nucleophilic Co-SIMP

Scattering off Nucleons



$$E_R \approx v_{\rm rel}^2 \frac{\mu^2}{M_{\rm SM}}$$



Detectors with lower energy thresholds ≈ eV

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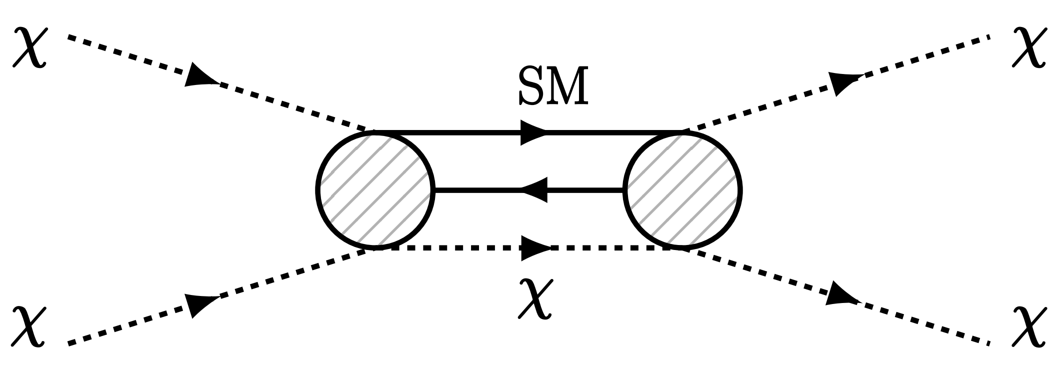
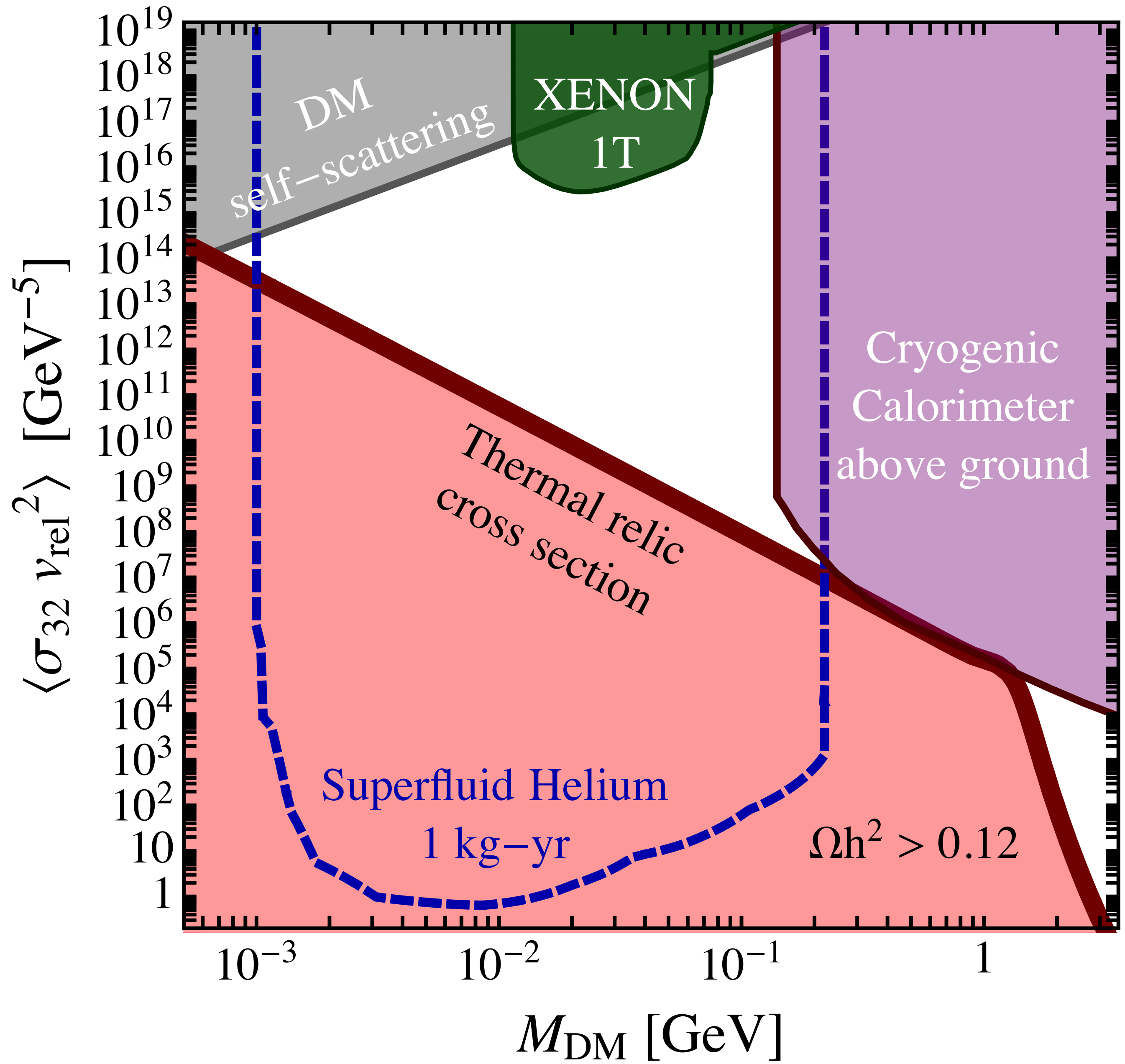
Dark Matter Self Interactions



$$\frac{\sigma_{\chi\chi}}{m_\chi} < \frac{\mathrm{cm}^2}{\mathrm{g}}$$



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