Dark Matter Catalyzed Baryon Destruction

Robert McGehee

University of Minnesota

5/20/25

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Institut Henri Poincaré

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Part I

DM turns neutrons into neutrinos

R McGehee

Part I

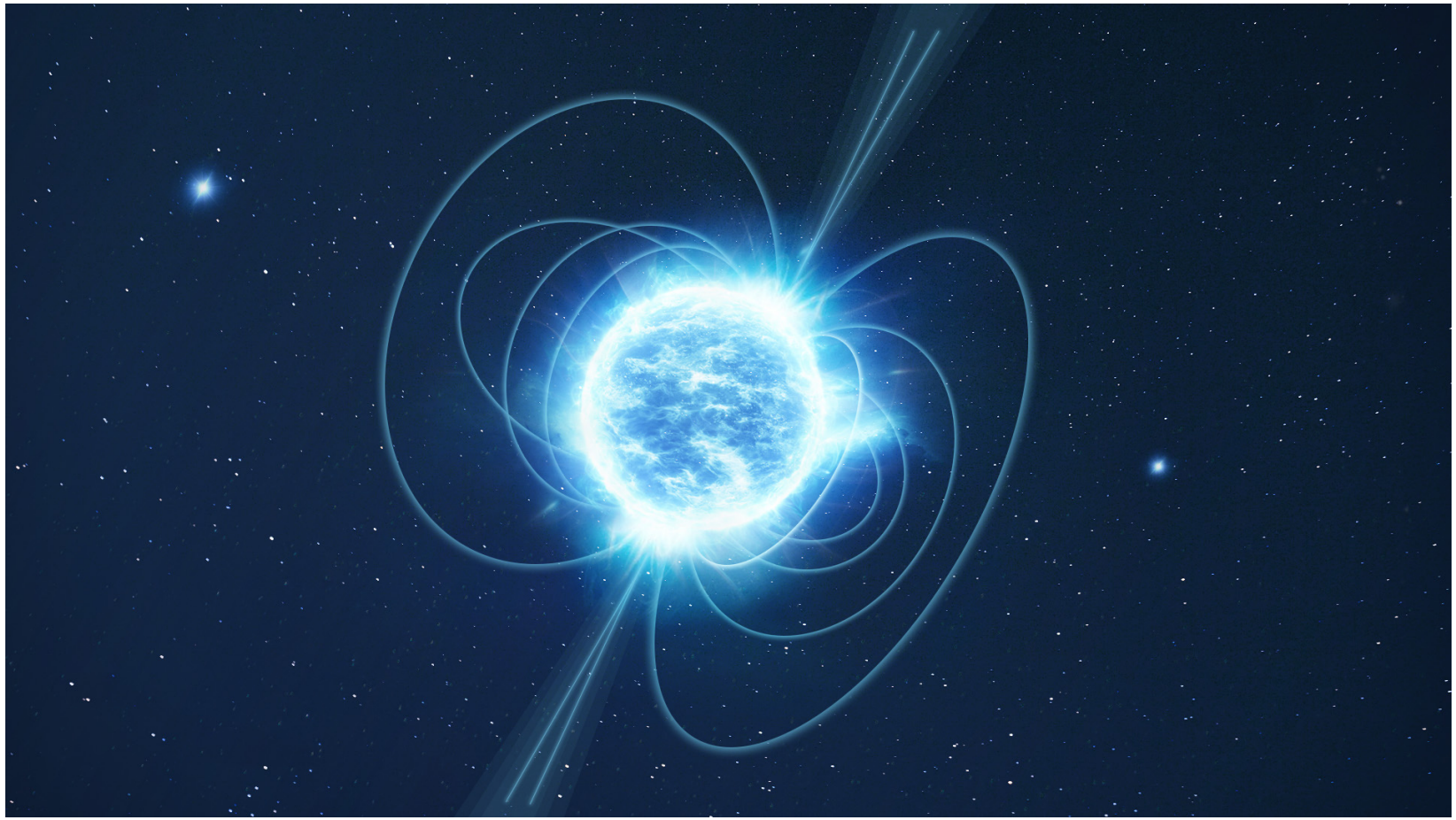
DM turns neutrons into neutrinos

Part II

Neutrons turn DM into neutrinos

R McGehee

Dark Matter Catalyzed Baryon Destruction



2405.18472
w/ Yohei Ema,
Maxim Pospelov,
& Anupam Ray

ϟ Motivation ϟ

Baryon asymmetry requires baryon-number-violating (BNV) processes

R McGehee

ϟ Motivation ϟ

Baryon asymmetry requires baryon-number-violating (BNV) processes

$\Omega_{\mathrm{DM}} \approx 5\Omega_{\mathrm{b}}$ implies DM creation and baryogenesis may be related

R McGehee

Motivation

Baryon asymmetry requires baryon-number-violating (BNV) processes

$\Omega_{\rm DM} \approx 5\Omega_{\rm b}$ implies DM creation and baryogenesis may be related

What if DM has BNV interactions?

Y. Ema, **RM**, M. Pospelov, & A. Ray
Phys. Rev. D 111 (2025) 023005
[2405.18472]

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$\mathcal{O}$(GeV) Energy when DM hits a baryon!

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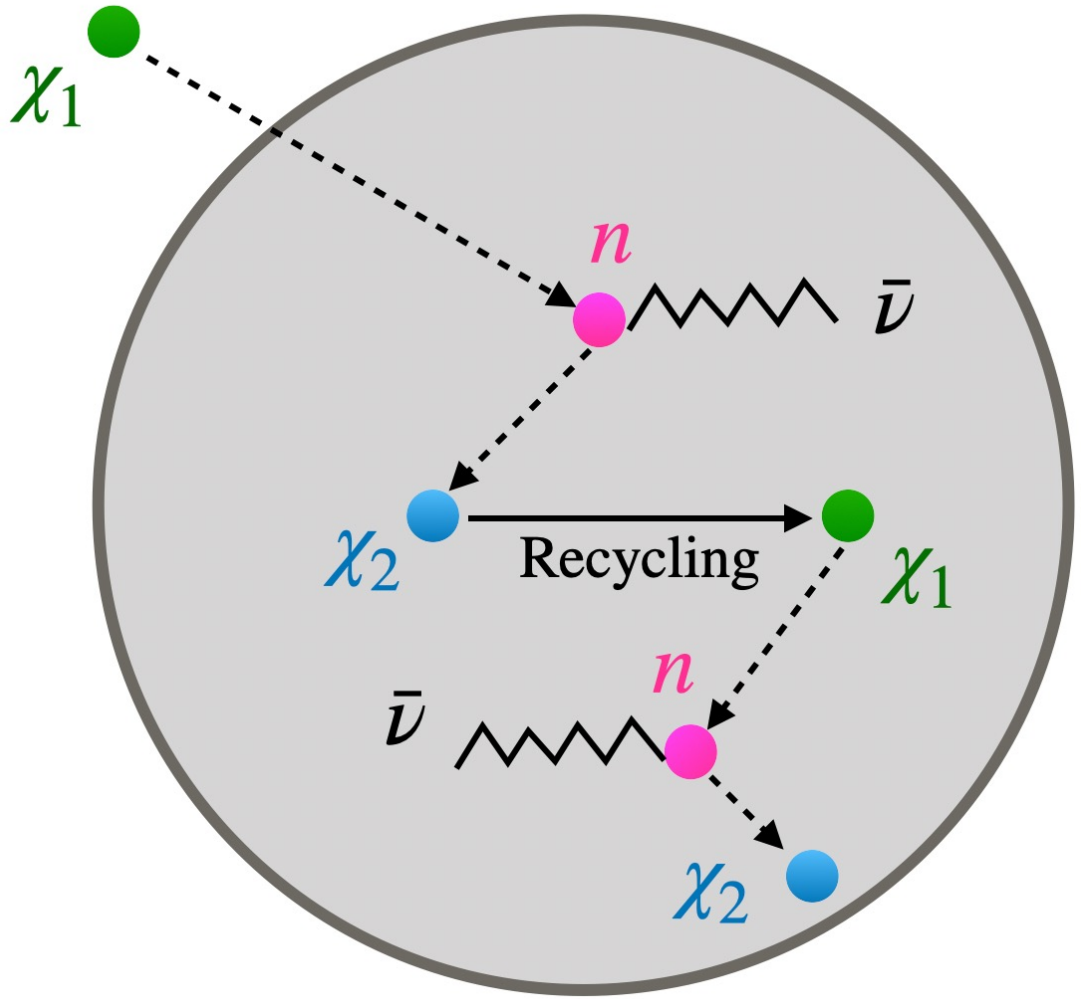
$\mathcal{O}$(GeV) Energy when DM hits a baryon!



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Neutron Star Heating

$$N_{\chi_1} \approx \mathbf{Min}\left(1, \sigma_{\chi n}/\sigma_{\rm th}\right)\sqrt{\frac{6}{\pi}}\,\frac{\rho_\chi}{m_\chi}\pi R_\star^2\,\bar{v}\,\frac{v_{\rm esc}^2}{\bar{v}^2}\,t_\star$$

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Neutron Star Heating

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$$\frac{dE_{\rm heat}}{dt} = N_{\chi_1} \times v\sigma_{\rm BNV} \times n_n m_n$$

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Neutron Star Heating

$$N_{\chi_1} \approx \mathbf{Min}\left(1, \sigma_{\chi n}/\sigma_{\rm th}\right)\sqrt{\frac{6}{\pi}}\,\frac{\rho_\chi}{m_\chi}\pi R_\star^2\,\bar{v}\,\frac{v_{\rm esc}^2}{\bar{v}^2}\,t_\star$$

$$\frac{dE_{\rm heat}}{dt} = N_{\chi_1} \times v\sigma_{\rm BNV} \times n_n m_n$$

$$\frac{dE_{\rm loss}}{dt} = 4\pi R_\star^2 \sigma_{\rm SB} T_\star^4$$

$$= 6.4 \times 10^{38}\,\frac{\rm eV}{\rm s}\left(\frac{R_\star}{11\,\rm km}\right)^2\left(\frac{T_\star}{2.85\,\rm eV}\right)^4$$

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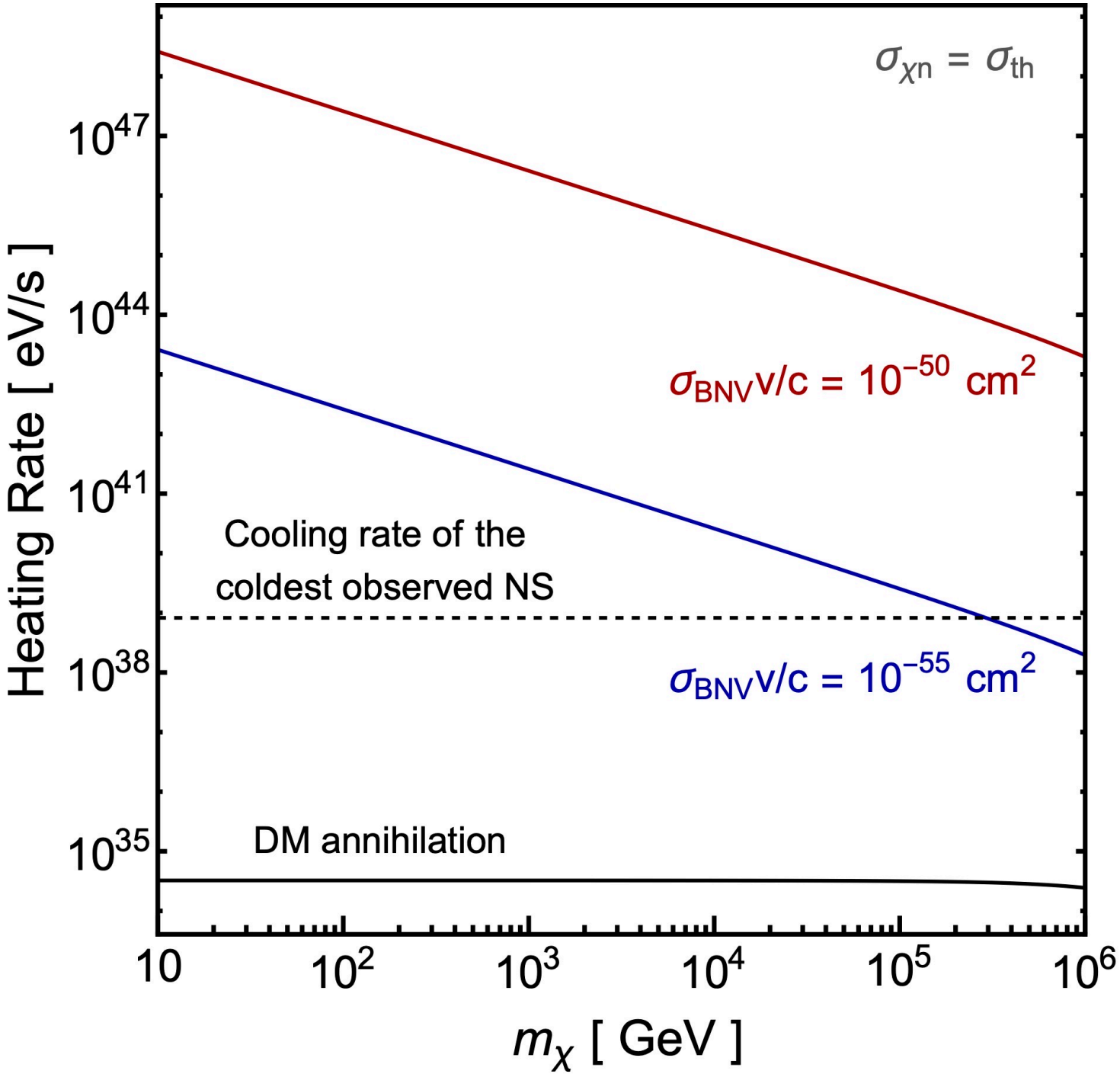
$\sigma_{\chi n} = \sigma_{th}$
$\sigma_{BNV} v/c = 10^{-50}$ cm^2
$\sigma_{BNV} v/c = 10^{-55}$ cm^2
Cooling rate of the
coldest observed NS
DM annihilation
Heating Rate [eV/s]
10^{47}
10^{44}
10^{41}
10^{38}
10^{35}
10
10^2
10^3
10^4
10^5
10^6
m_χ [GeV]

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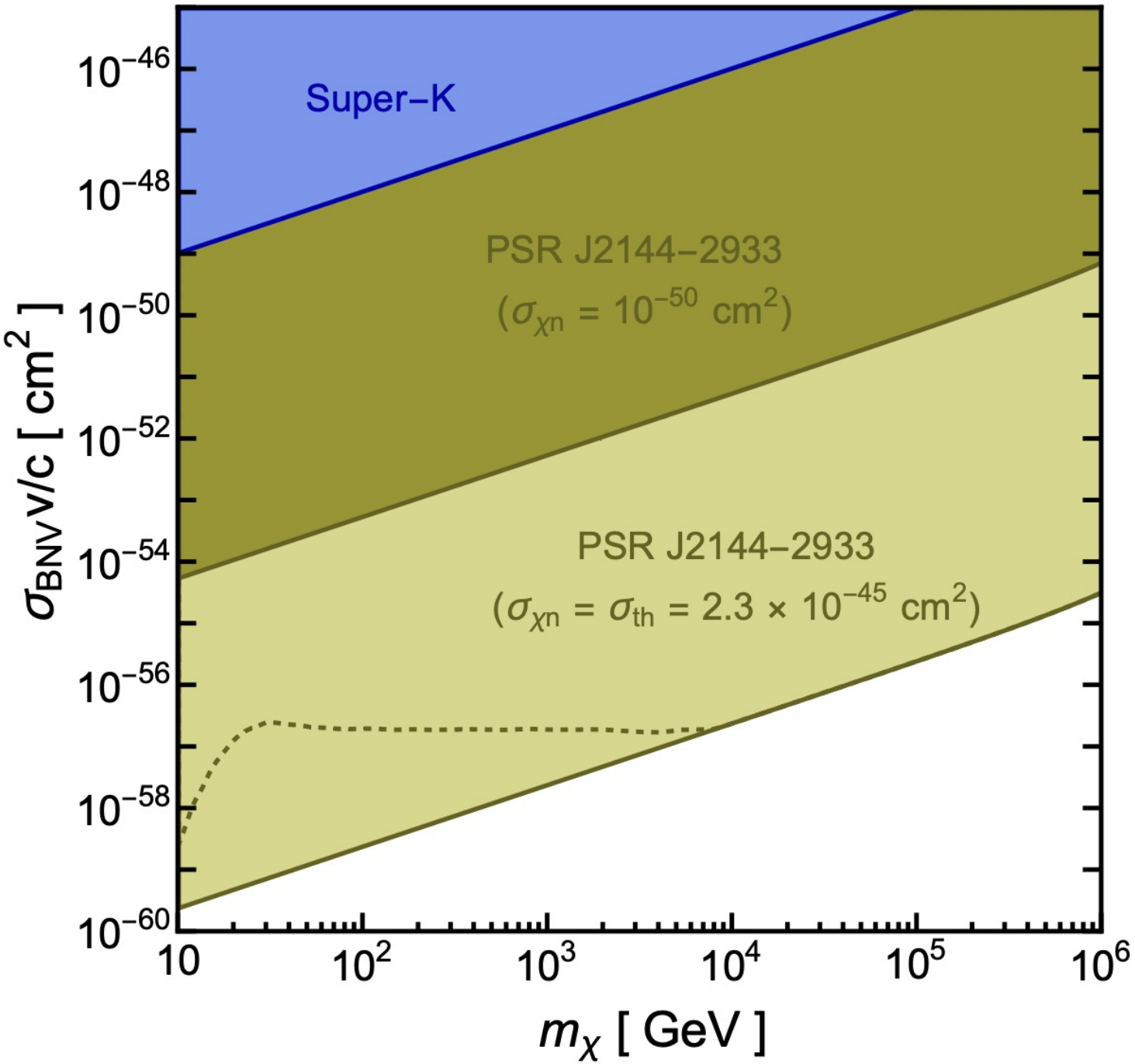
Super–K
PSR J2144–2933
($\sigma_{\chi n}$ = 10^{-50} cm^2)
PSR J2144–2933
($\sigma_{\chi n}$ = σ_{th} = 2.3 × 10^{-45} cm^2)
σ_{BNV}v/c [cm^2]
m_χ [GeV]
10^{-46}
10^{-48}
10^{-50}
10^{-52}
10^{-54}
10^{-56}
10^{-58}
10^{-60}
10
10^2
10^3
10^4
10^5
10^6

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A Simple Toy Model

$$\mathcal{L} = G_{\mathrm{BNV}} \bar{\chi}_2 \gamma_\mu \chi_1 \times \left(\overline{e^+} \gamma^\mu p + \bar{\bar{\nu}} \gamma^\mu n \right) + (\mathrm{h.\,c.}),$$

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A Simple Toy Model

$$\mathcal{L} = G_{\mathrm{BNV}} \bar{\chi}_2 \gamma_\mu \chi_1 \times \left(\overline{e^+} \gamma^\mu p + \bar{\bar{\nu}} \gamma^\mu n \right) + (\mathrm{h.\,c.}),$$
$$+ G_\chi \left(\bar{\chi}_1 \gamma_\mu \chi_1 + \bar{\chi}_2 \gamma_\mu \chi_2 \right) \left(\bar{p} \gamma^\mu p + \bar{n} \gamma^\mu n \right),$$

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A Simple Toy Model

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$$+ G_\chi \left(\bar{\chi}_1 \gamma_\mu \chi_1 + \bar{\chi}_2 \gamma_\mu \chi_2 \right) \left(\bar{p} \gamma^\mu p + \bar{n} \gamma^\mu n \right),$$
$$- \frac{\Delta m_\chi}{2} \bar{\chi}_2 \chi_1 + (\mathrm{h.\,c.}).$$

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Fast...

$$\frac{\Delta m_\chi}{m_\chi} \gtrsim 6 \times 10^{-28} \left(\frac{100\,\mathrm{GeV}}{m_\chi} \right) \left(\frac{\sigma_{\mathrm{BNV}} v/c}{10^{-50}\,\mathrm{cm}^2} \right).$$

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Fast…but not too fast

$$\frac{\Delta m_\chi}{m_\chi} \gtrsim 6 \times 10^{-28} \left(\frac{100\,\mathrm{GeV}}{m_\chi} \right) \left(\frac{\sigma_{\mathrm{BNV}} v/c}{10^{-50}\,\mathrm{cm}^2} \right).$$

$$\frac{\Delta m_\chi}{m_\chi} \lesssim 10^{-7} \left(\frac{10^{-50}\,\mathrm{cm}^2}{\sigma_{\mathrm{BNV}} v/c} \right)^{1/2} \left(\frac{10^{-45}\,\mathrm{cm}^2}{\sigma_{\chi n}} \right)^{1/2}.$$

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- Since B-L is conserved, can we construct a full DM- & baryo-genesis framework which has these interesting signals?

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- Since B-L is conserved, can we construct a full DM- & baryo-genesis framework which has these interesting signals?
- Should SK perform a dedicated search for nucleon semi-annihilation to improve bounds?

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AND NOW FOR
SOMETHING
COMPLETELY
DIFFERENT

Part I

DM turns neutrons into neutrinos

Part II

Neutrons turn DM into neutrinos

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Fermionic Absorption DM

J. Dror, G. Elor, & **RM**	Phys. Rev. Lett. 124 (2020) 18	[1905.12635]
J. Dror, G. Elor, & **RM**	JHEP 02 (2020) 134	[1908.10861]
J. Dror, G. Elor, **RM**, & T.-T. Yu	Phys. Rev. D 103 (2021) 3	[2011.01940]

What if DM wasn't absolutely stable?

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What if DM wasn't absolutely stable?

$$\chi + e^- \to \nu + e^- \qquad \overset{(-)}{\chi} + {}^{A}_{Z}\mathrm{X} \to \overset{(-)}{\nu} + {}^{A}_{Z}\mathrm{X}$$

$$\overset{(-)}{\chi} + {}^{A}_{Z}\mathrm{X} \to e^{\pm} + {}^{A}_{Z\mp1}\mathrm{X}^{(*)}$$

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"Neutral current" operators lead to peaked recoils.
"Charged current" operators induce β decays with extra signals.
Either way, these are distinct from WIMP-y elastic recoils.

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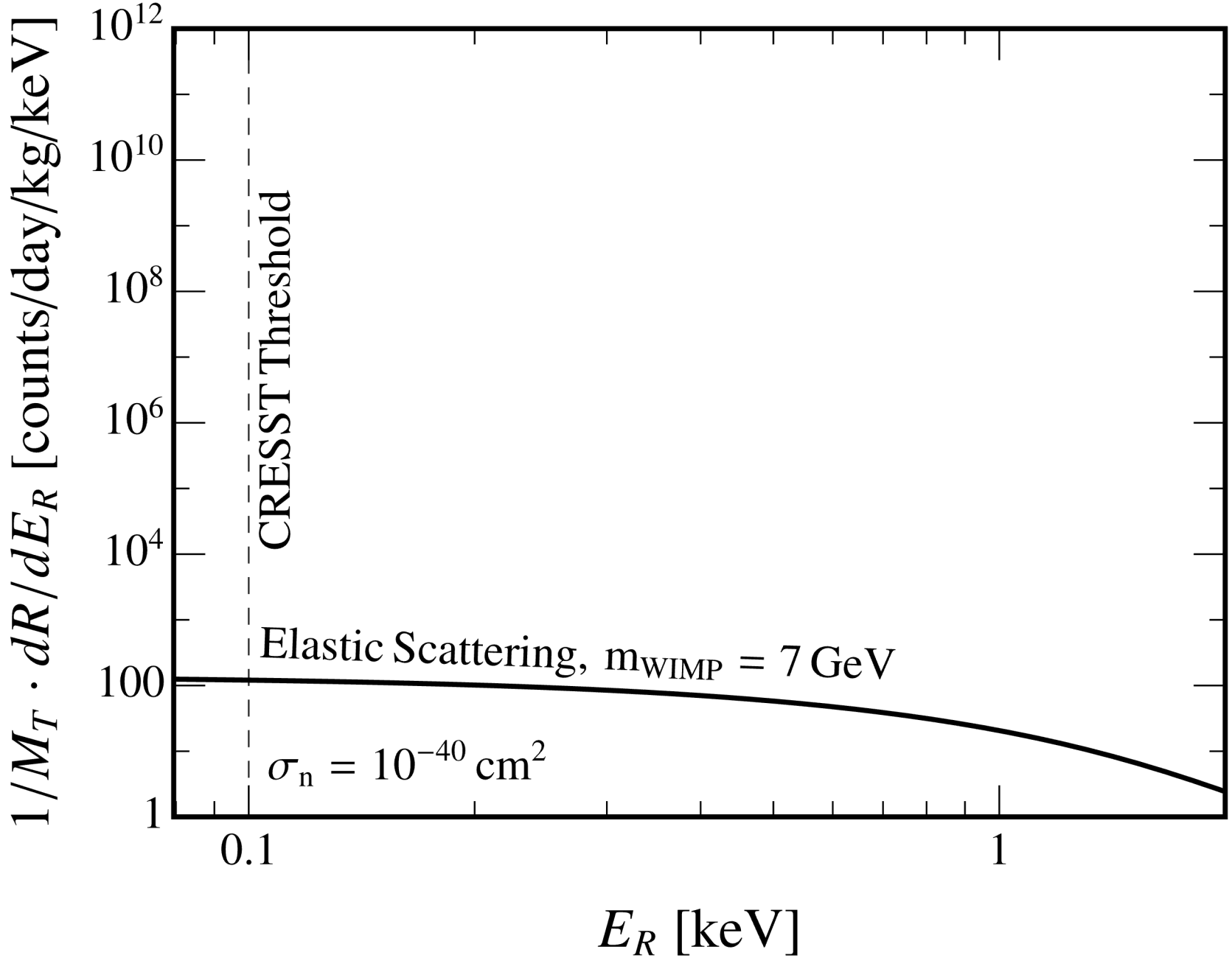
Scattering in CRESST



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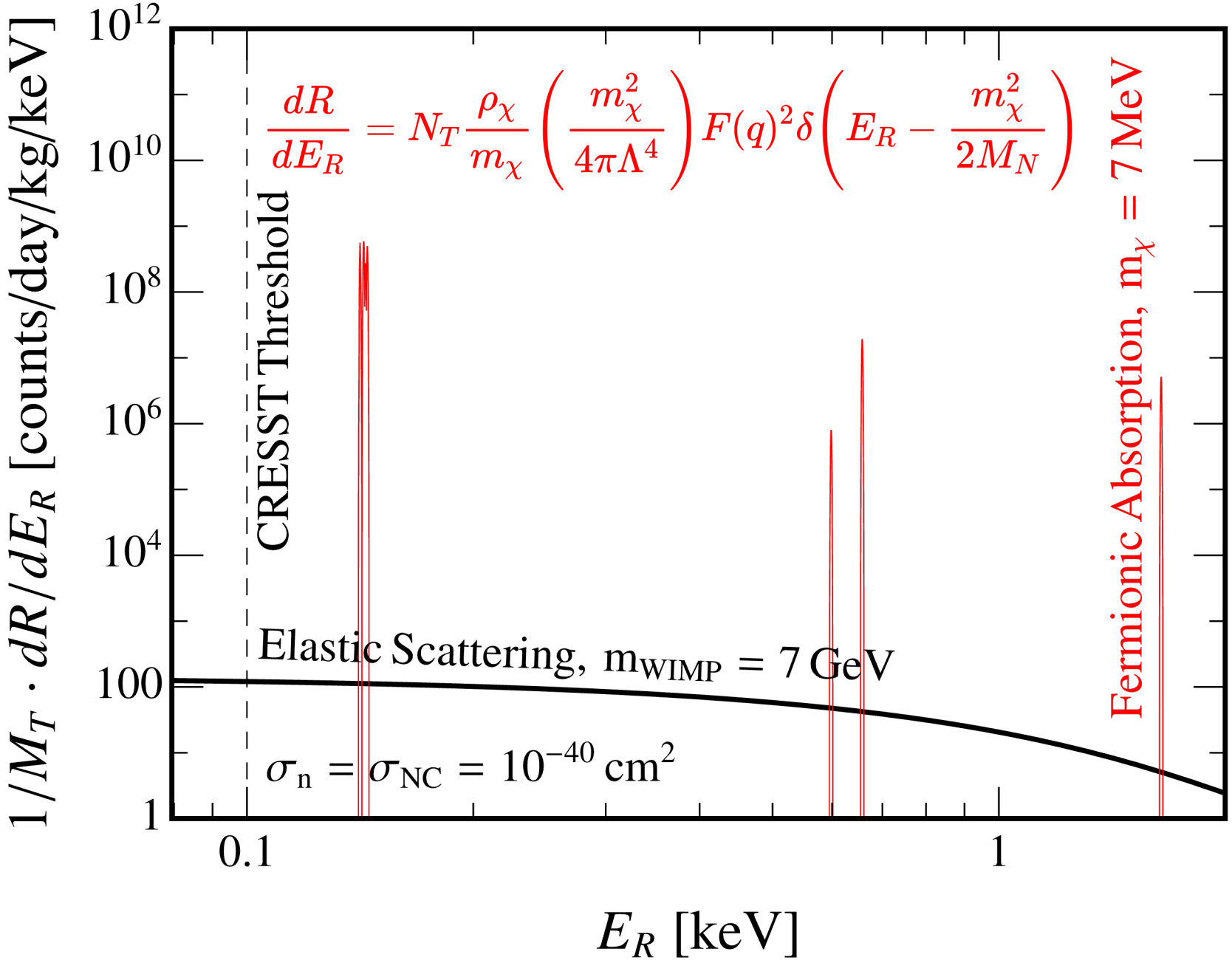
Scattering in CRESST



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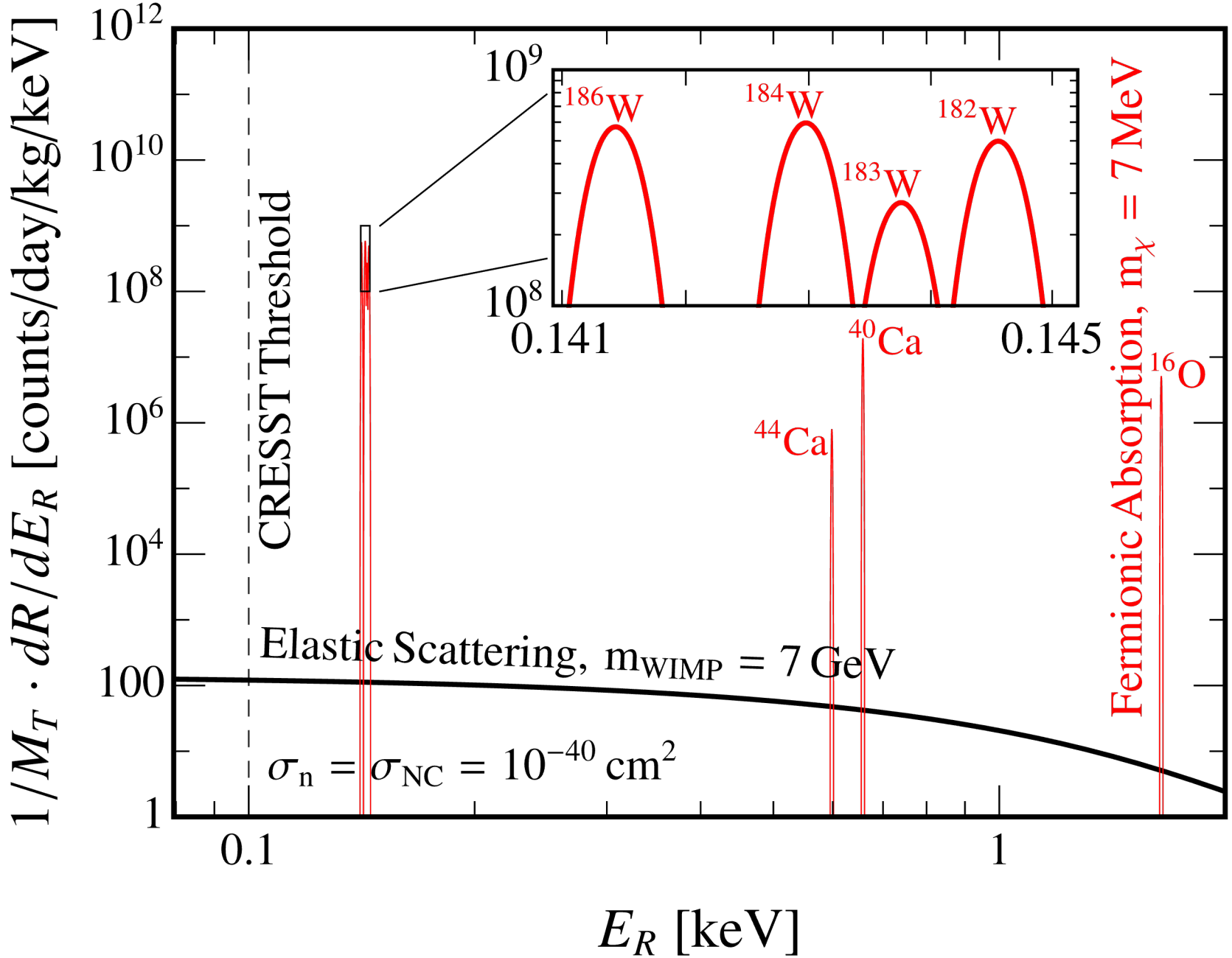
Scattering in CRESST



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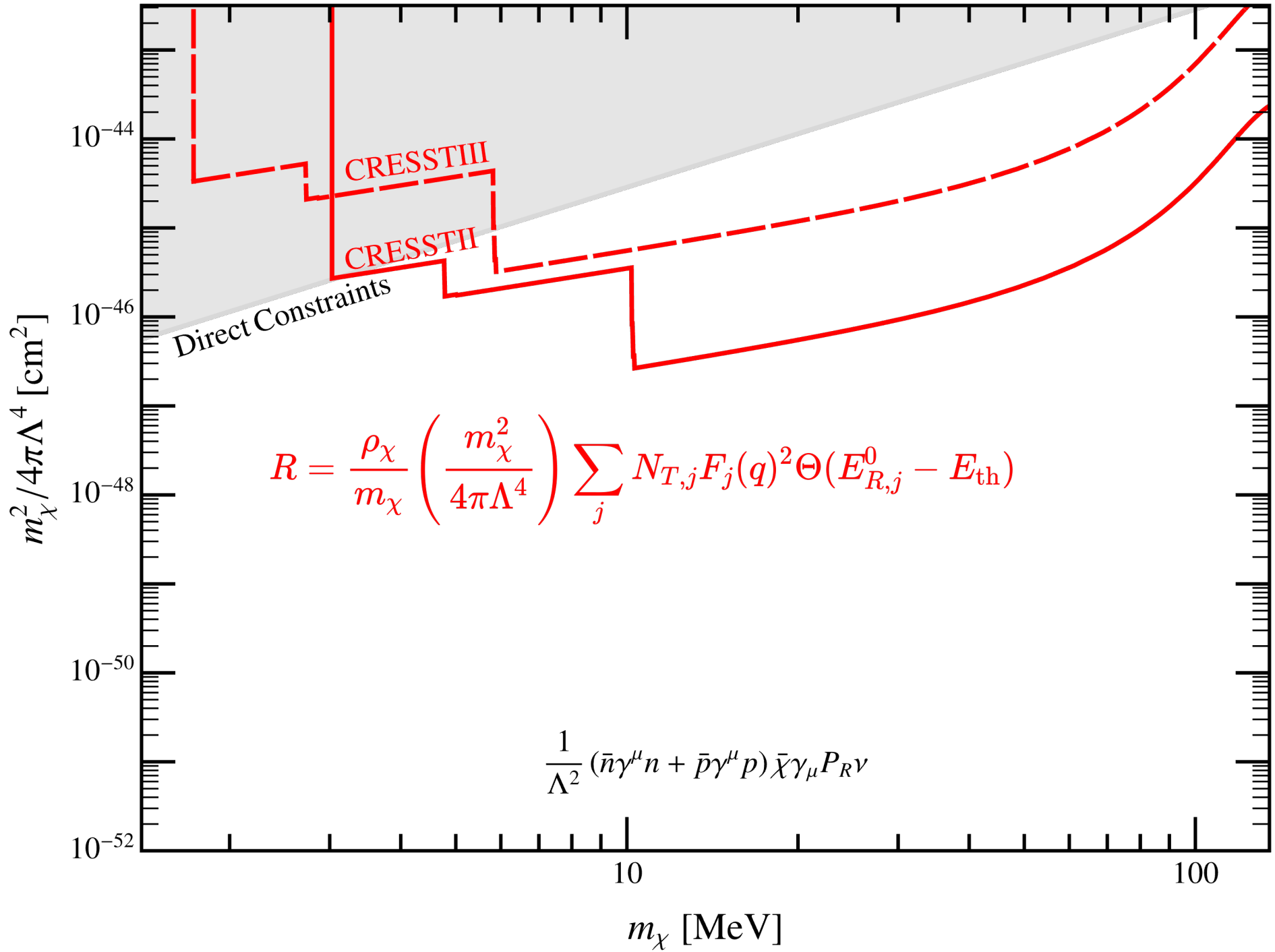
CRESSTIII
CRESSTII
Direct Constraints
$R = \frac{\rho_\chi}{m_\chi}\left(\frac{m_\chi^2}{4\pi\Lambda^4}\right)\sum_j N_{T,j}F_j(q)^2\Theta(E^0_{R,j} - E_{\rm th})$
$\frac{1}{\Lambda^2}(\bar{n}\gamma^\mu n + \bar{p}\gamma^\mu p)\,\bar{\chi}\gamma_\mu P_R\nu$
10^{-44}
10^{-46}
10^{-48}
10^{-50}
10^{-52}
$m_\chi^2/4\pi\Lambda^4$ [cm^2]
10
100
m_χ [MeV]

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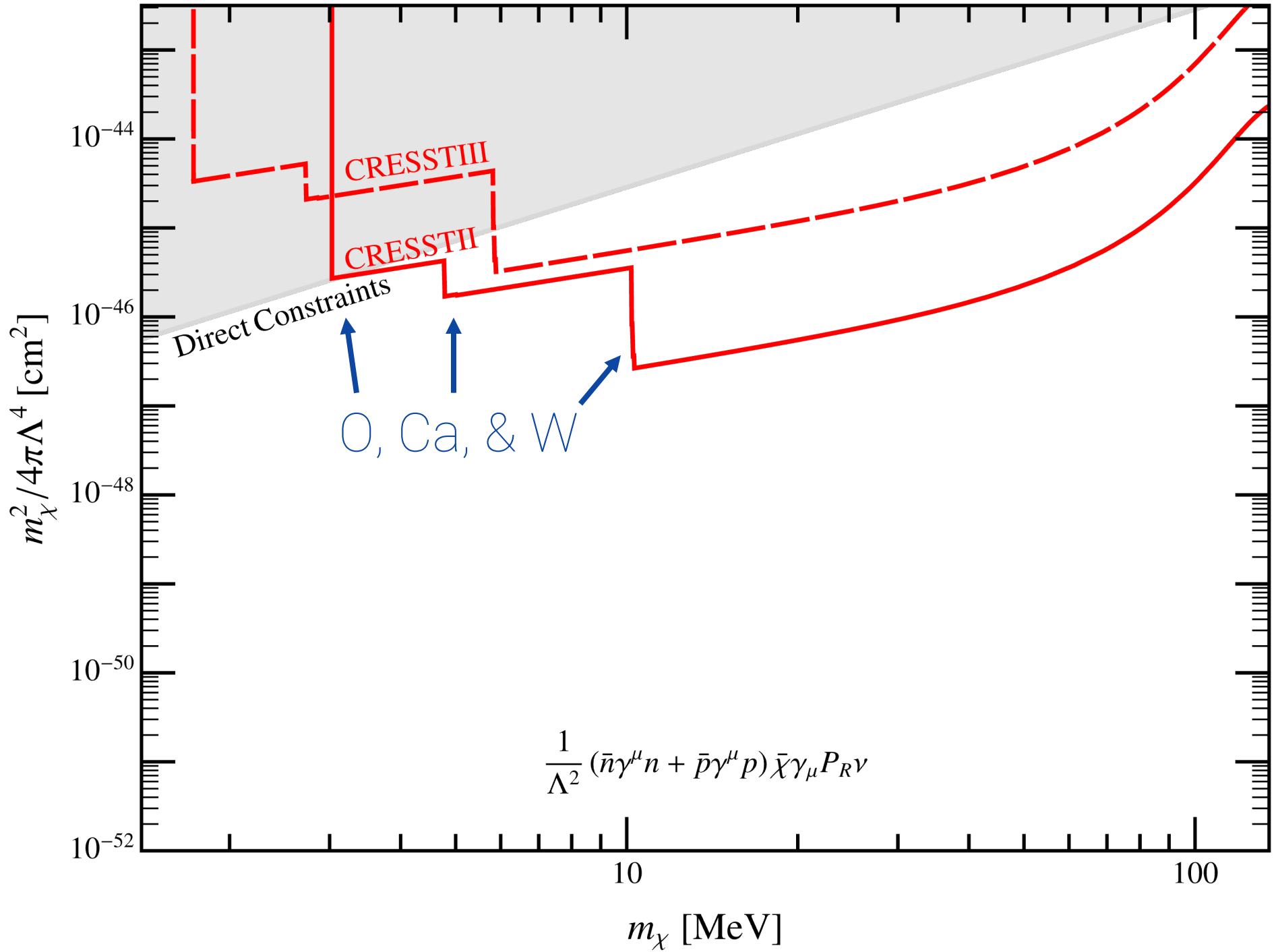
CRESSTIII
CRESSTII
Direct Constraints
O, Ca, & W
$\frac{1}{\Lambda^2}(\bar{n}\gamma^\mu n + \bar{p}\gamma^\mu p)\bar{\chi}\gamma_\mu P_R \nu$
$m_\chi^2/4\pi\Lambda^4$ [cm^2]
10^{-44}
10^{-46}
10^{-48}
10^{-50}
10^{-52}
10
100
m_χ [MeV]

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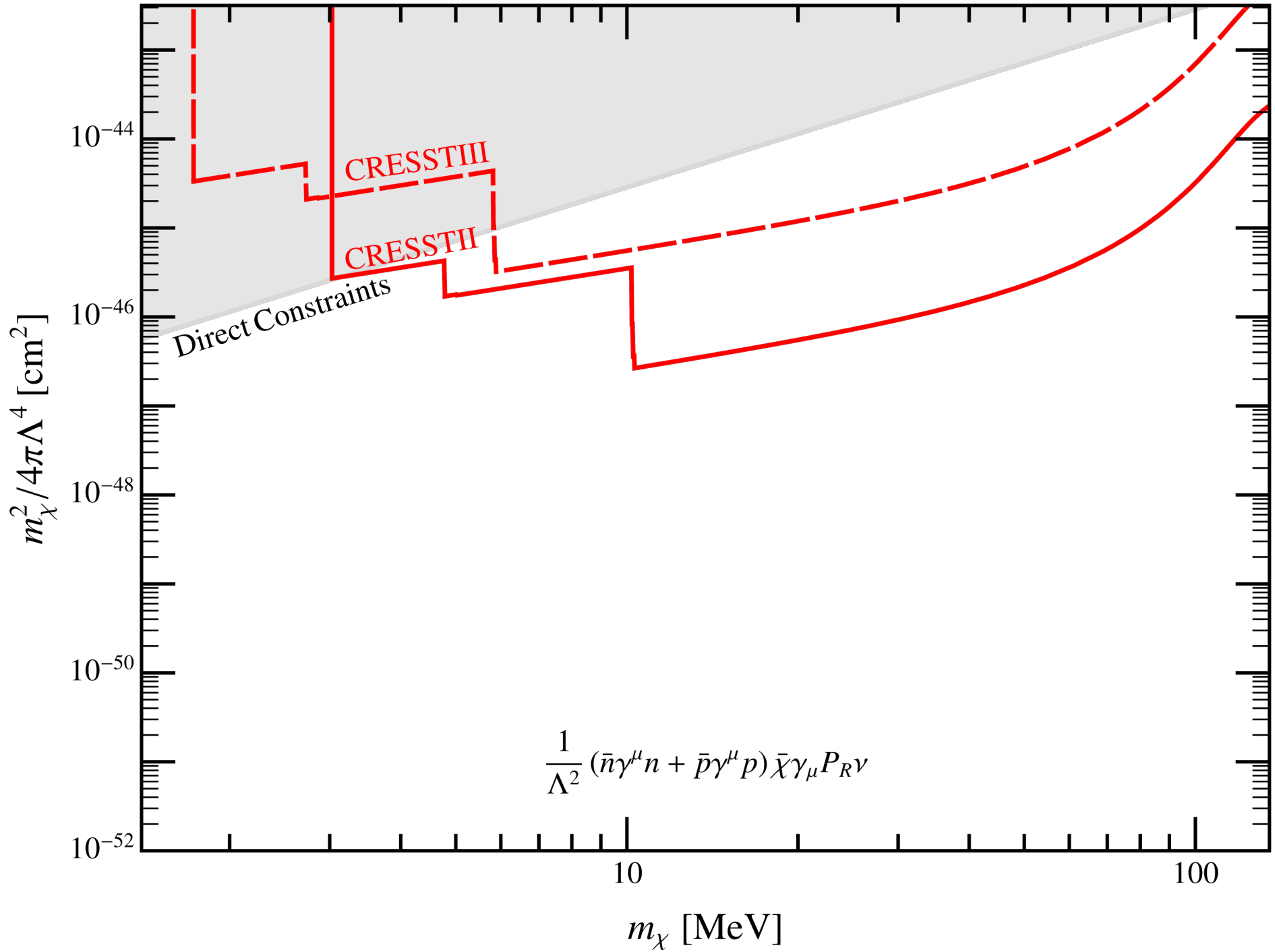
CRESSTIII
CRESSTII
Direct Constraints
10^{-44}
10^{-46}
10^{-48}
10^{-50}
10^{-52}
$m_\chi^2/4\pi\Lambda^4$ [cm^2]
$\frac{1}{\Lambda^2}(\bar{n}\gamma^\mu n + \bar{p}\gamma^\mu p)\,\bar{\chi}\gamma_\mu P_R \nu$
10
100
m_χ [MeV]

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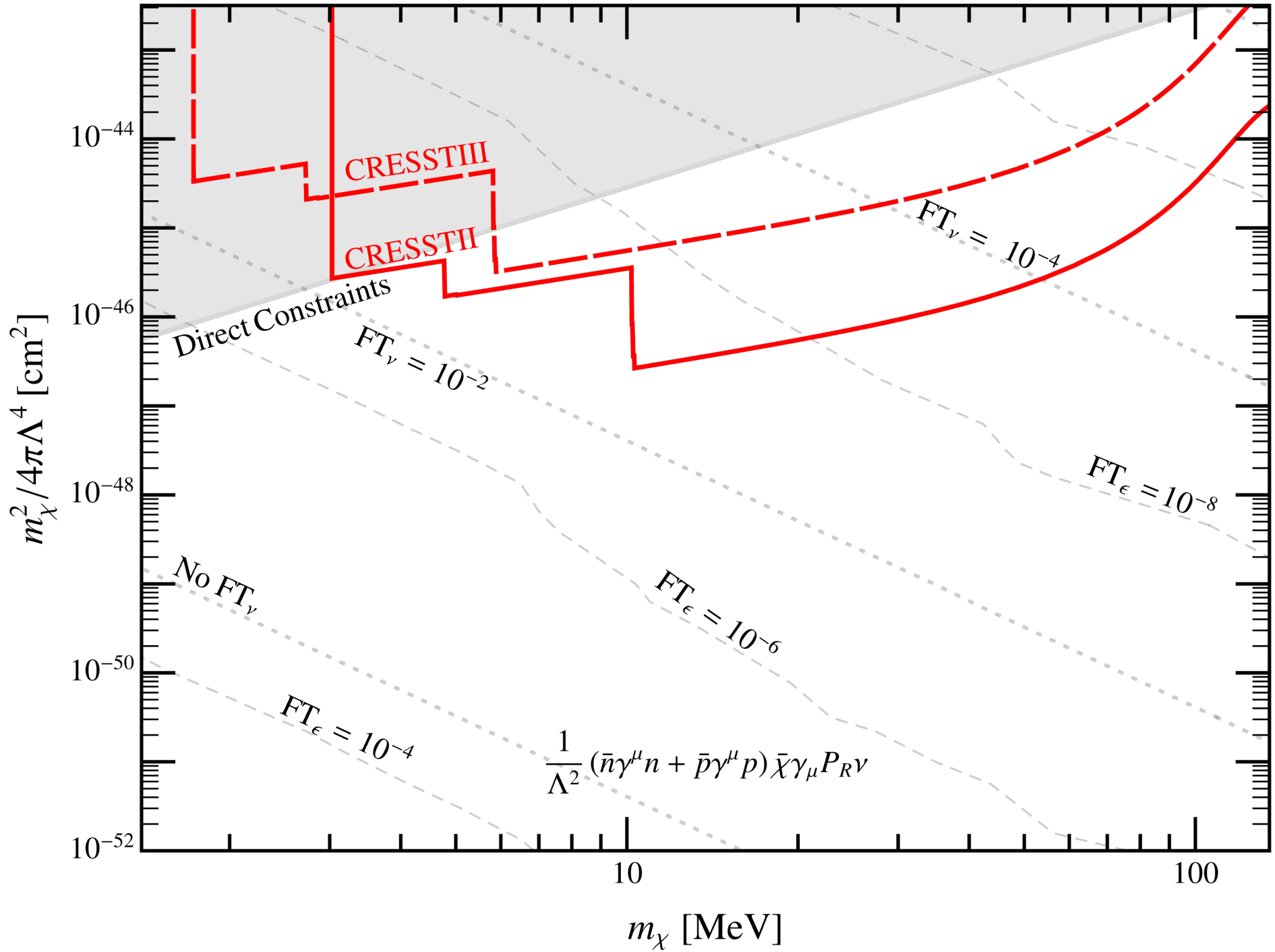
CRESSTIII
CRESSTII
Direct Constraints
$FT_\nu = 10^{-4}$
$FT_\nu = 10^{-2}$
$FT_\epsilon = 10^{-8}$
$FT_\epsilon = 10^{-6}$
No FT_ν
$FT_\epsilon = 10^{-4}$
$\frac{1}{\Lambda^2}(\bar{n}\gamma^\mu n + \bar{p}\gamma^\mu p)\,\bar{\chi}\gamma_\mu P_R \nu$
10^{-44}
10^{-46}
10^{-48}
10^{-50}
10^{-52}
$m_\chi^2/4\pi\Lambda^4$ [cm^2]
10
100
m_χ [MeV]

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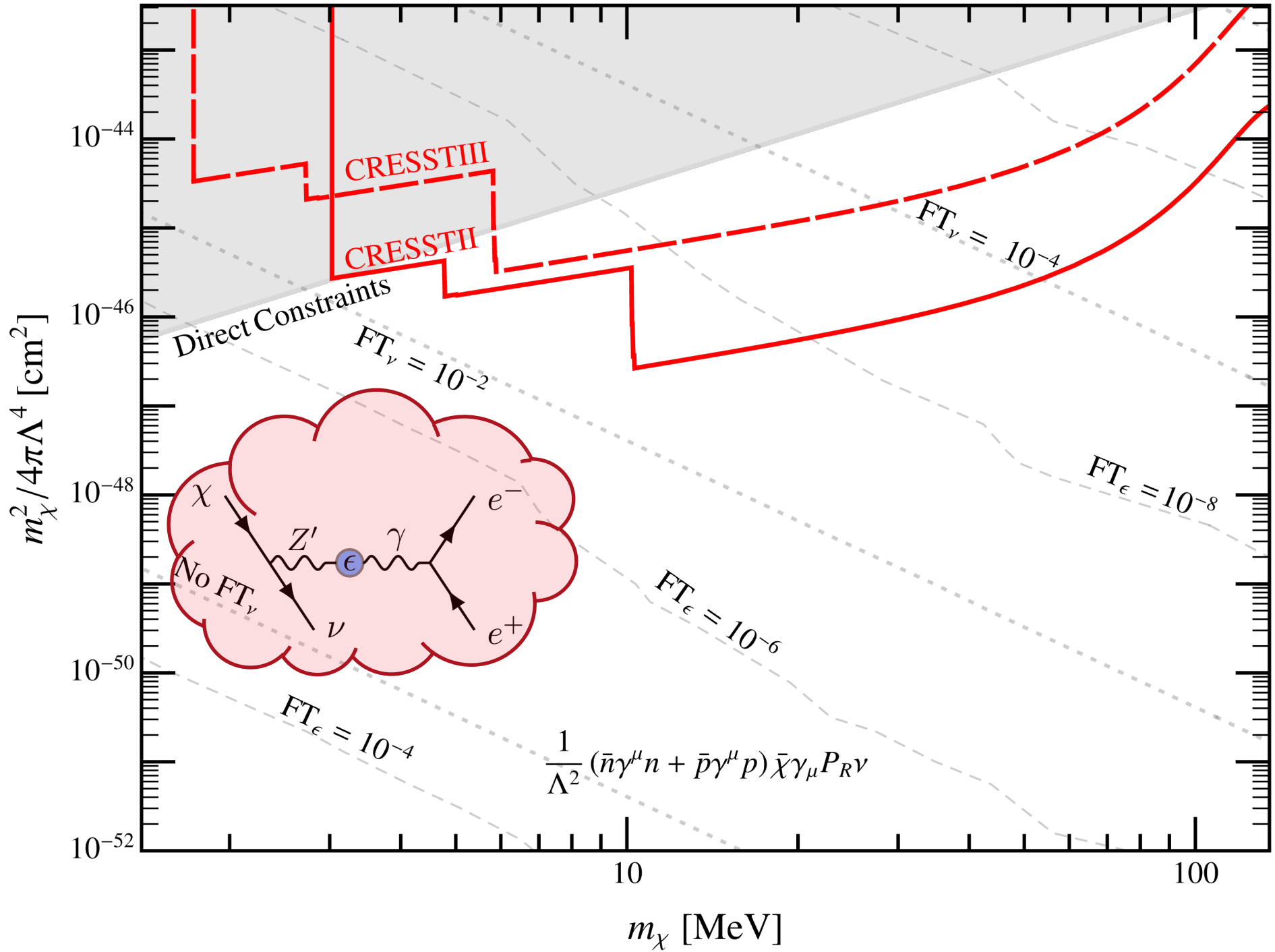
CRESSTIII
CRESSTII
Direct Constraints
$FT_\nu = 10^{-4}$
$FT_\nu = 10^{-2}$
$FT_\epsilon = 10^{-8}$
$FT_\epsilon = 10^{-6}$
$FT_\epsilon = 10^{-4}$
No FT_ν
χ
Z'
ϵ
γ
e^-
ν
e^+
$\frac{1}{\Lambda^2}(\bar{n}\gamma^\mu n + \bar{p}\gamma^\mu p)\bar{\chi}\gamma_\mu P_R \nu$
10^{-44}
10^{-46}
10^{-48}
10^{-50}
10^{-52}
$m_\chi^2/4\pi\Lambda^4$ [cm^2]
10
100
m_χ [MeV]

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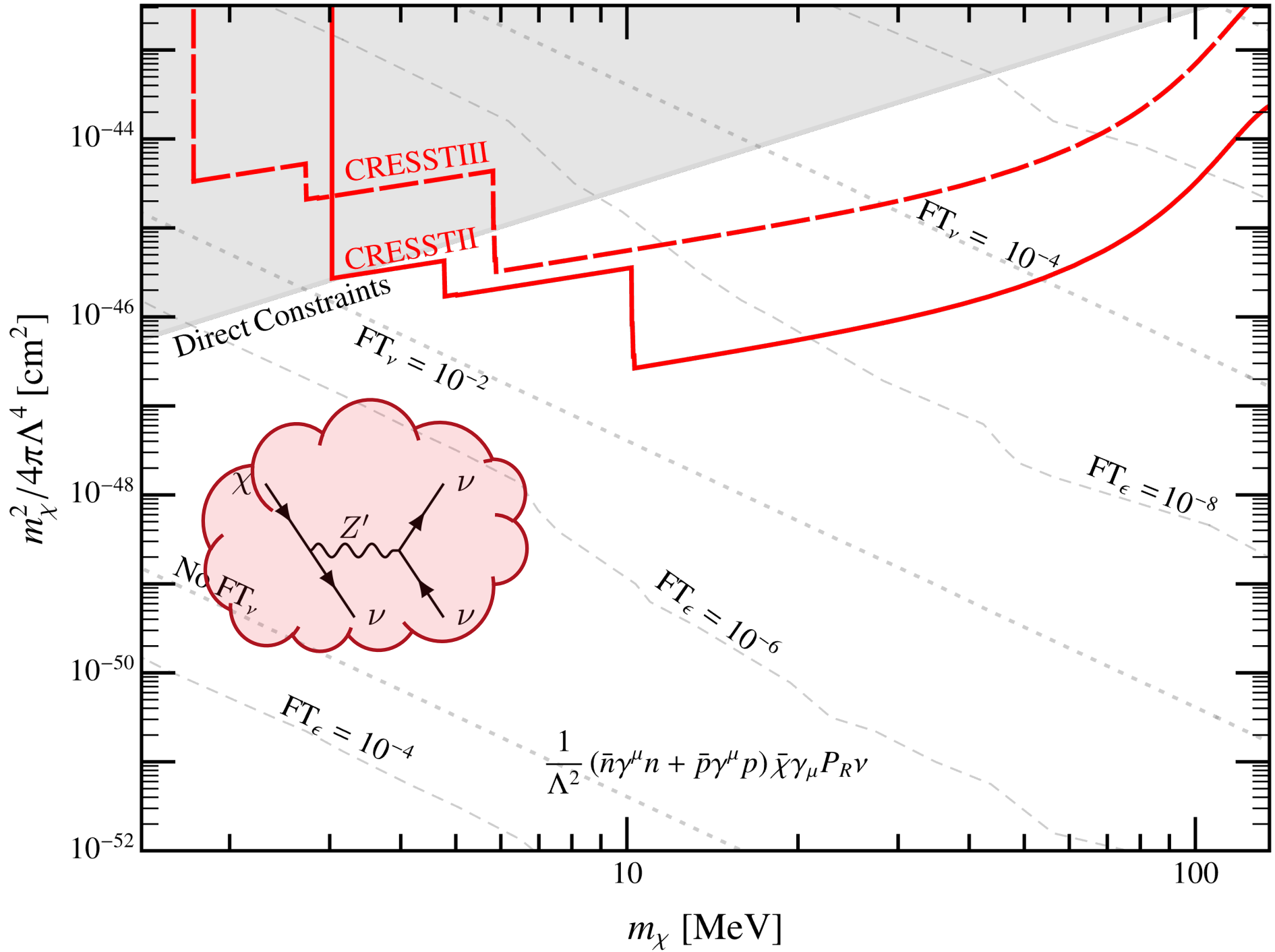
CRESSTIII
CRESSTII
Direct Constraints
$\mathrm{FT}_\nu = 10^{-4}$
$\mathrm{FT}_\nu = 10^{-2}$
$\mathrm{FT}_\epsilon = 10^{-8}$
$\mathrm{FT}_\epsilon = 10^{-6}$
$\mathrm{FT}_\epsilon = 10^{-4}$
No FT_ν
χ
Z'
ν
ν
ν
$\frac{1}{\Lambda^2}(\bar{n}\gamma^\mu n + \bar{p}\gamma^\mu p)\,\bar{\chi}\gamma_\mu P_R \nu$
10^{-44}
10^{-46}
10^{-48}
10^{-50}
10^{-52}
$m_\chi^2/4\pi\Lambda^4$ [cm^2]
10
100
m_χ [MeV]

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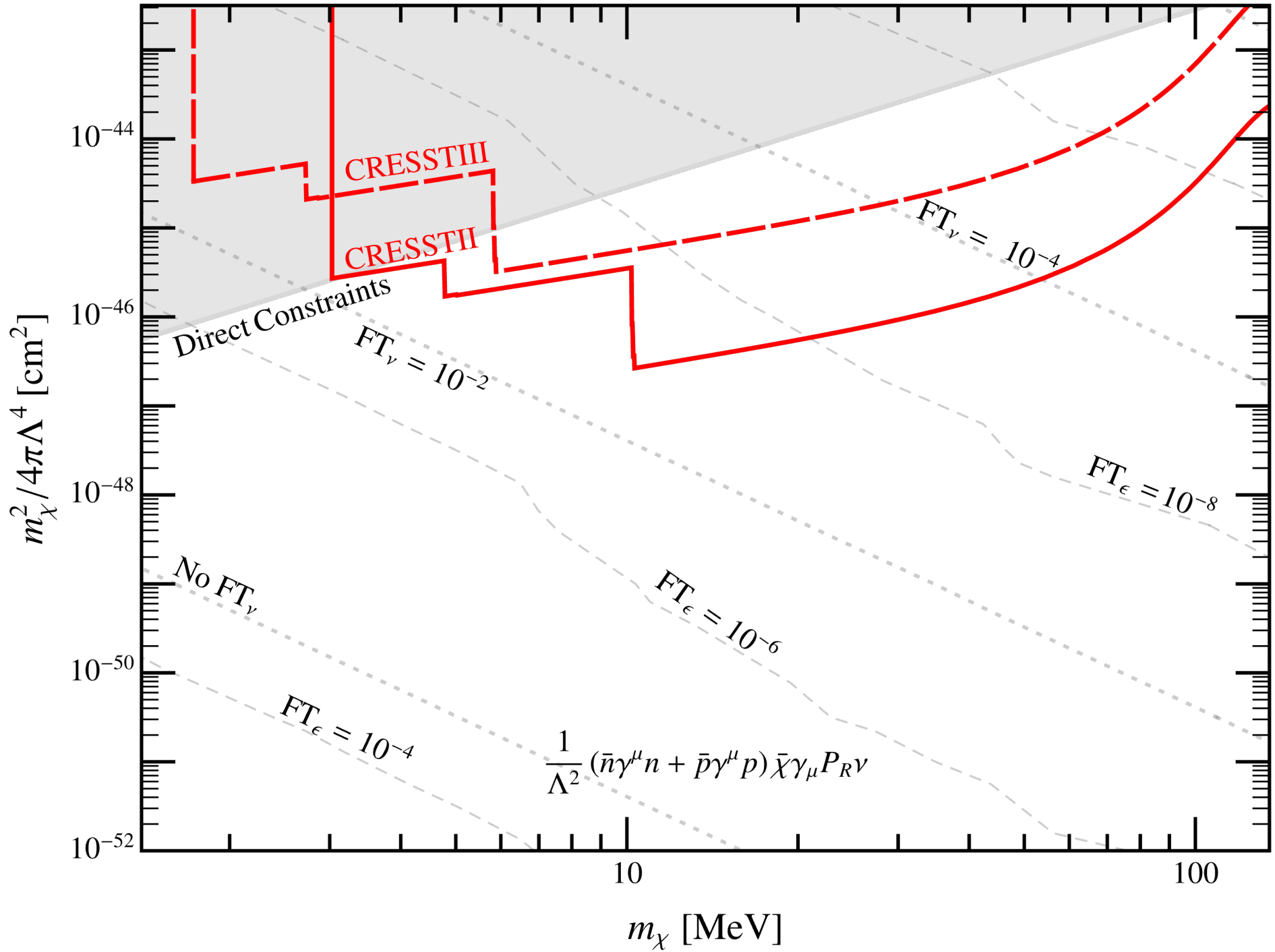
CRESSTIII
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Direct Constraints
$FT_\nu = 10^{-4}$
$FT_\nu = 10^{-2}$
$FT_\epsilon = 10^{-8}$
$FT_\epsilon = 10^{-6}$
No FT_ν
$FT_\epsilon = 10^{-4}$
$\frac{1}{\Lambda^2}(\bar{n}\gamma^\mu n + \bar{p}\gamma^\mu p)\,\bar{\chi}\gamma_\mu P_R \nu$
10^{-44}
10^{-46}
10^{-48}
10^{-50}
10^{-52}
$m_\chi^2/4\pi\Lambda^4$ [cm^2]
10
100
m_χ [MeV]

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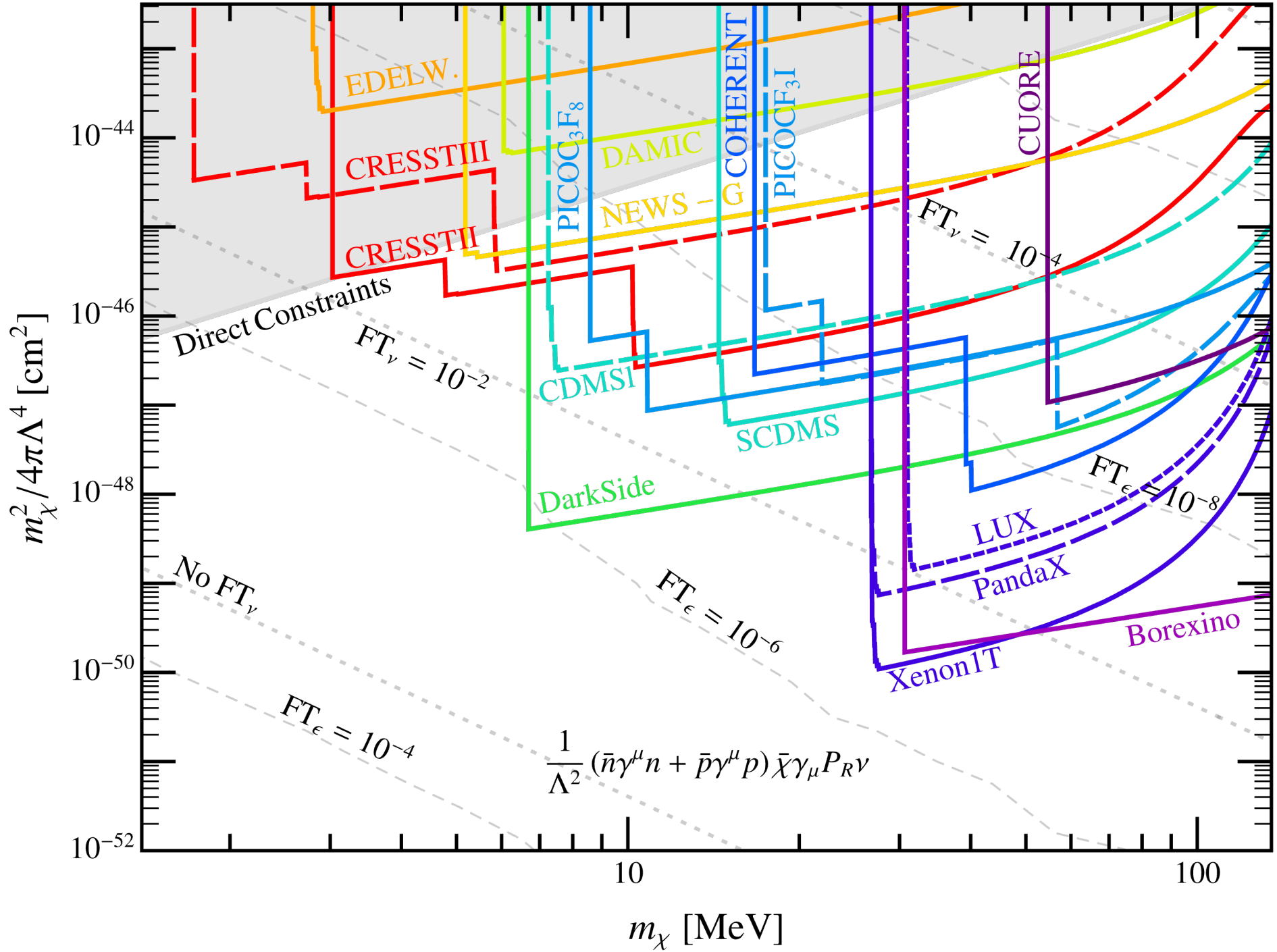
EDELW.
CRESSTIII
CRESSTII
PICOCF3I
DAMIC
NEWS − G
COHERENT
PICOC3F8
CUORE
Direct Constraints
FT_ν = 10^−2
FT_ν = 10^−4
CDMSI
SCDMS
DarkSide
FT_ε = 10^−8
LUX
PandaX
Borexino
Xenon1T
No FT_ν
FT_ε = 10^−6
FT_ε = 10^−4
(1/Λ^2) (n̄γ^μ n + p̄γ^μ p) χ̄γ_μ P_R ν
10^−44
10^−46
10^−48
10^−50
10^−52
10
100
m_χ [MeV]
m_χ^2/4πΛ^4 [cm^2]

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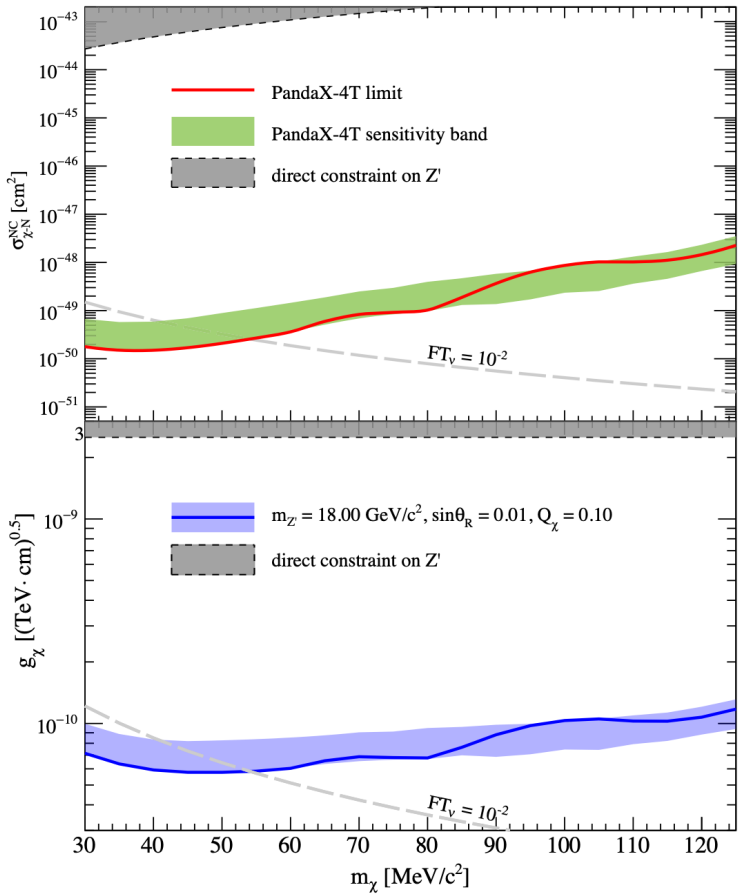
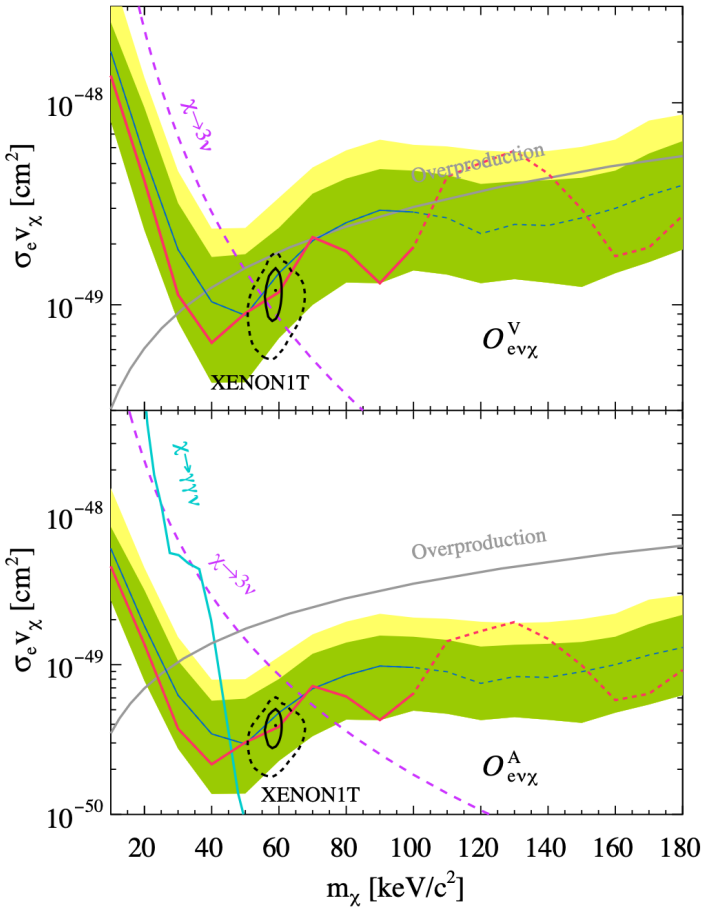
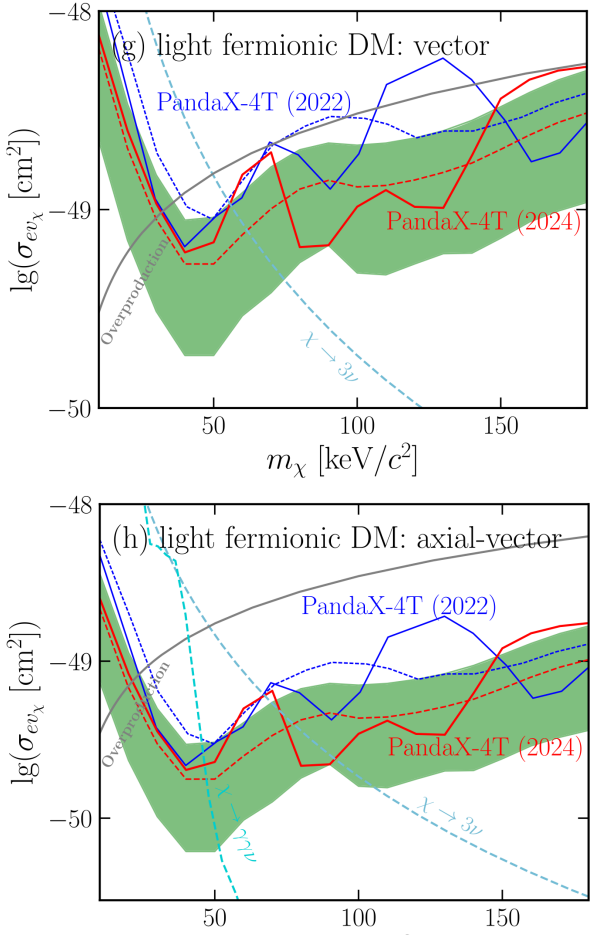
Fermionic Absorption DM



Phys. Rev. Lett. 129 (2022) 161803



Phys. Rev. Lett. 129 (2022) 161804



Phys. Rev. Lett. 134 (2025) 041001

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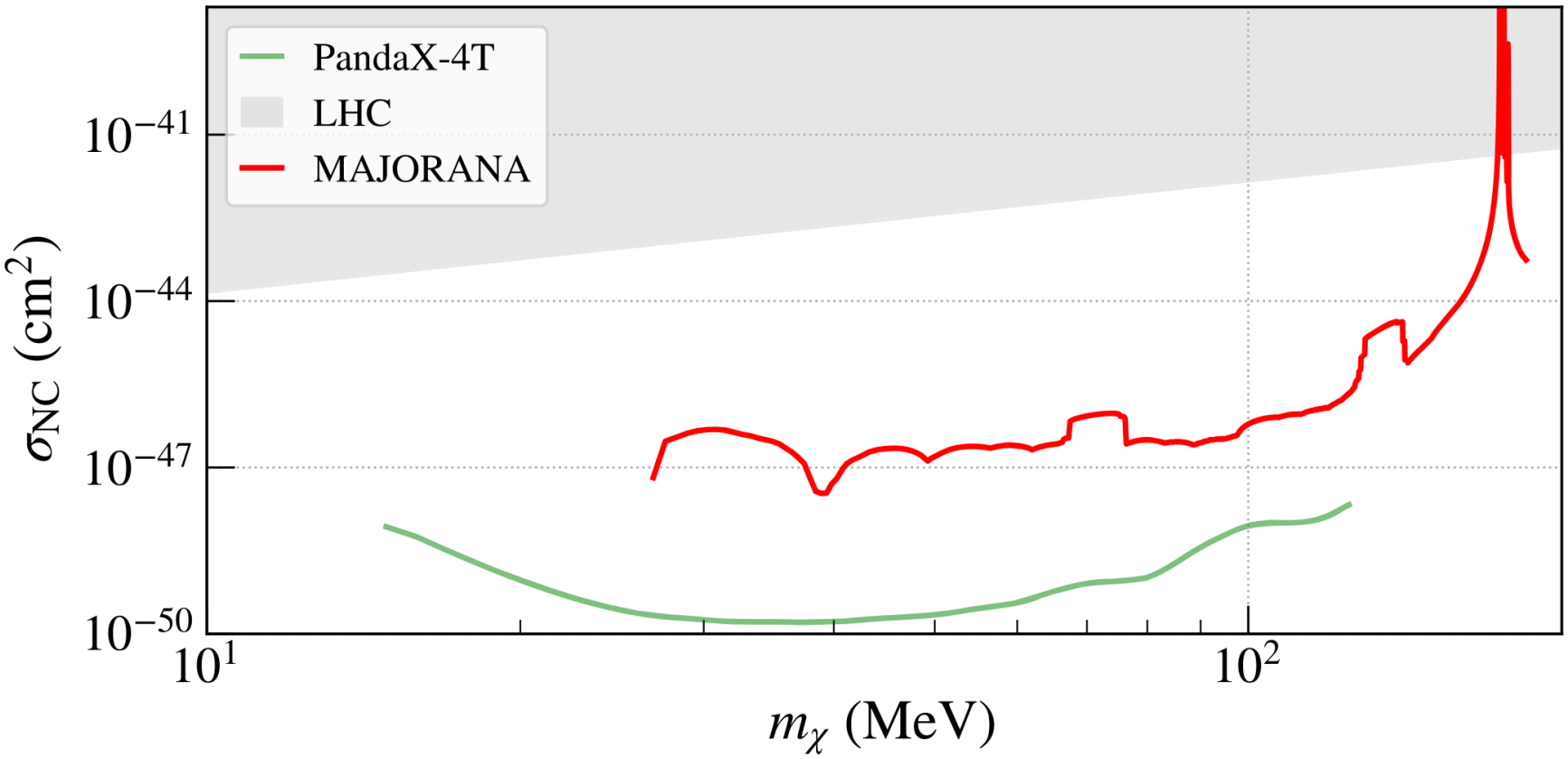
Fermionic Absorption DM



Phys. Rev. Lett. 132 (2024) 041001

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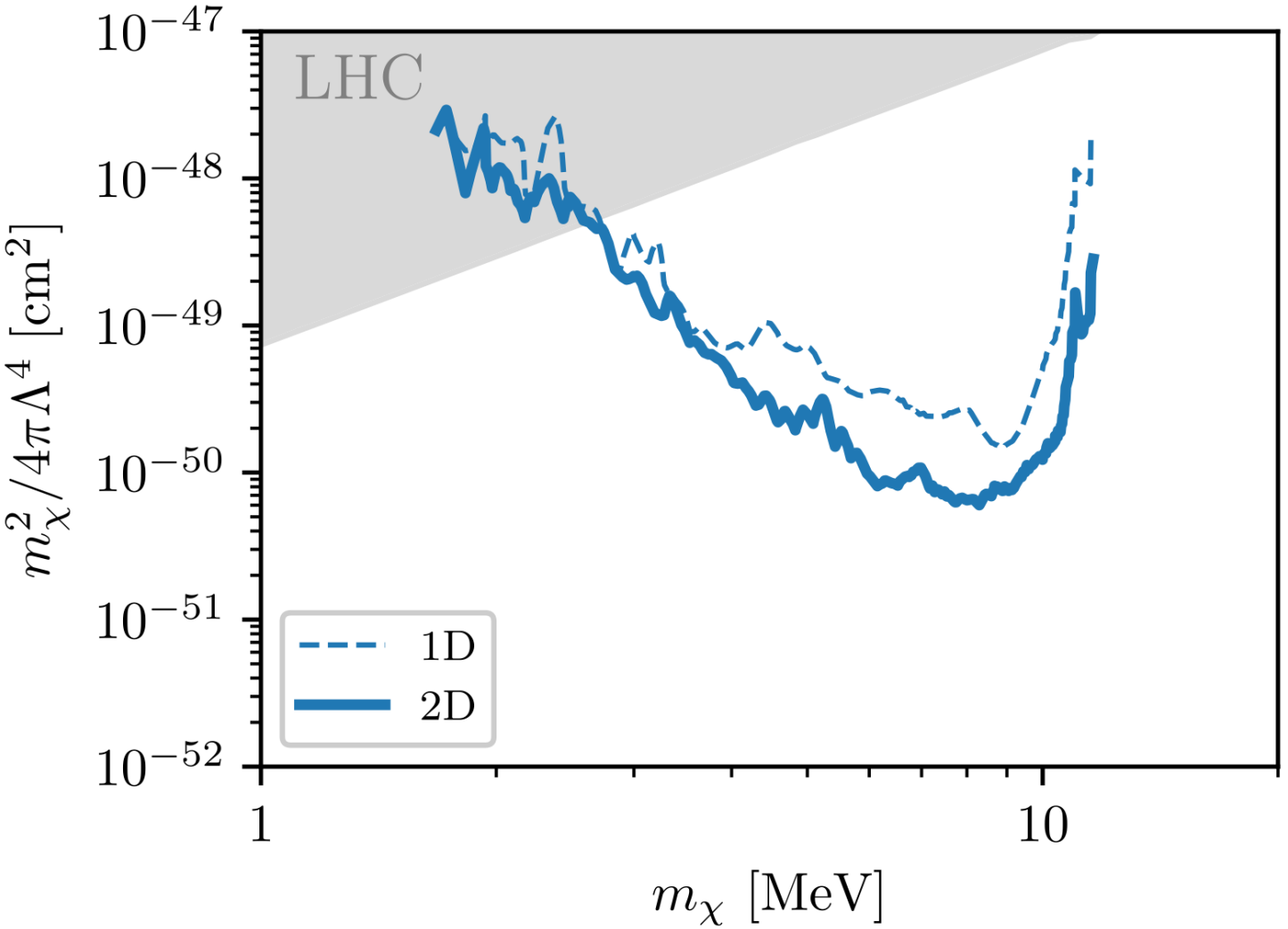
Fermionic Absorption DM



Phys. Rev. D 107 (2023) 012007

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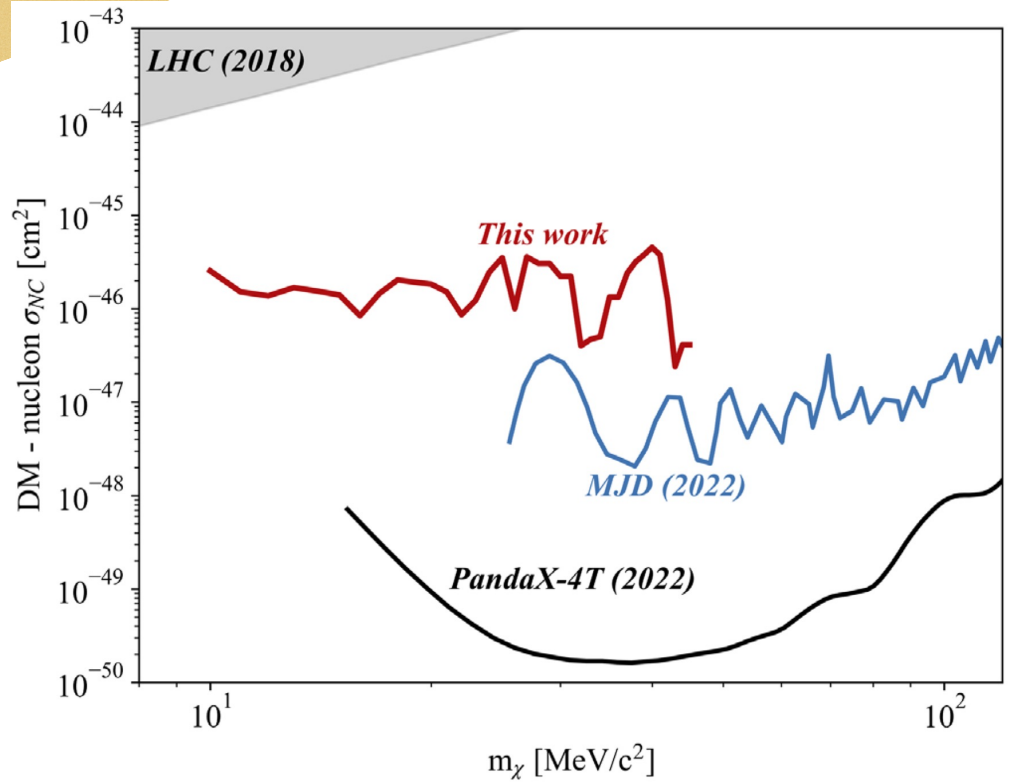
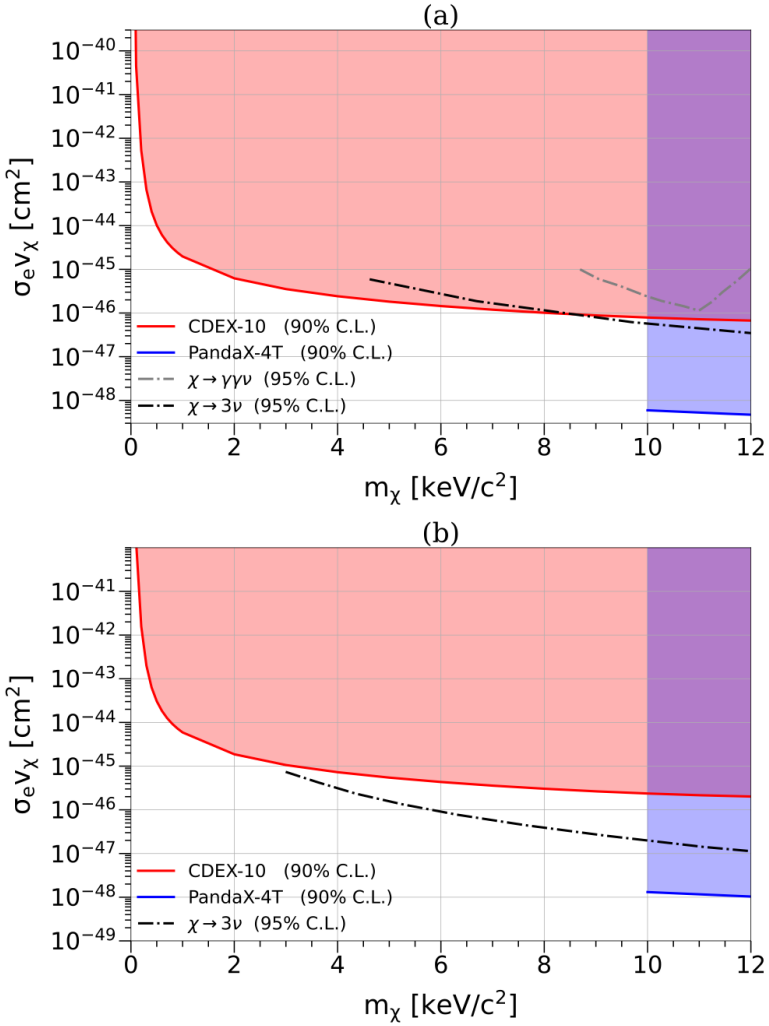


Phys. Rev. Lett. 129 (2022) 221802



[2404.09793]

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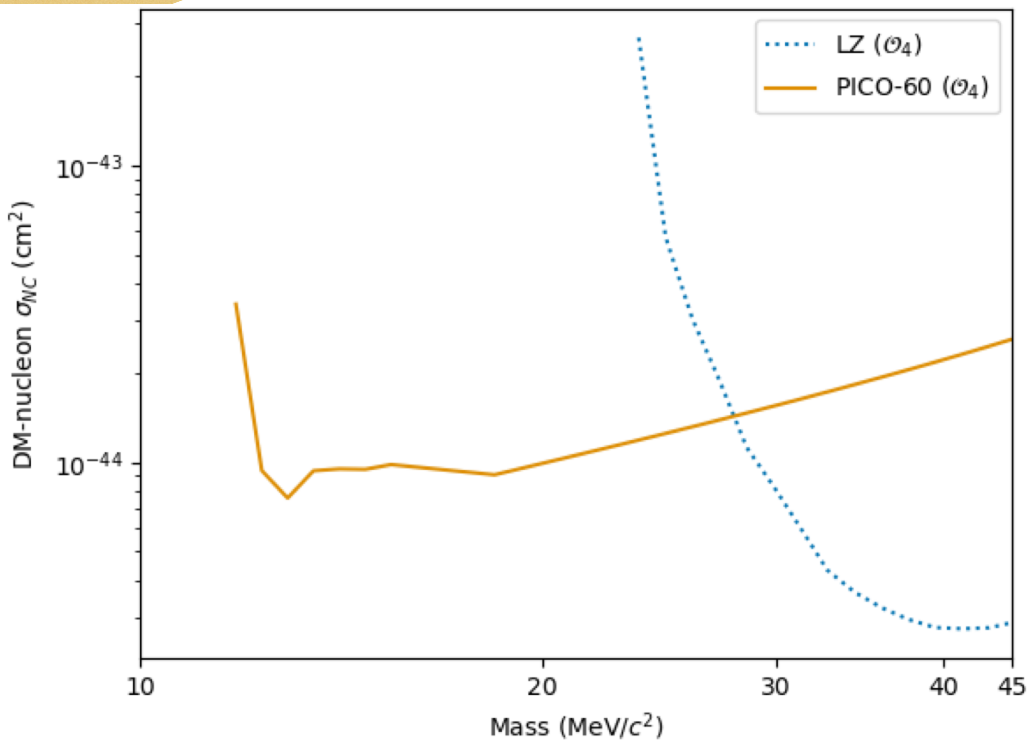

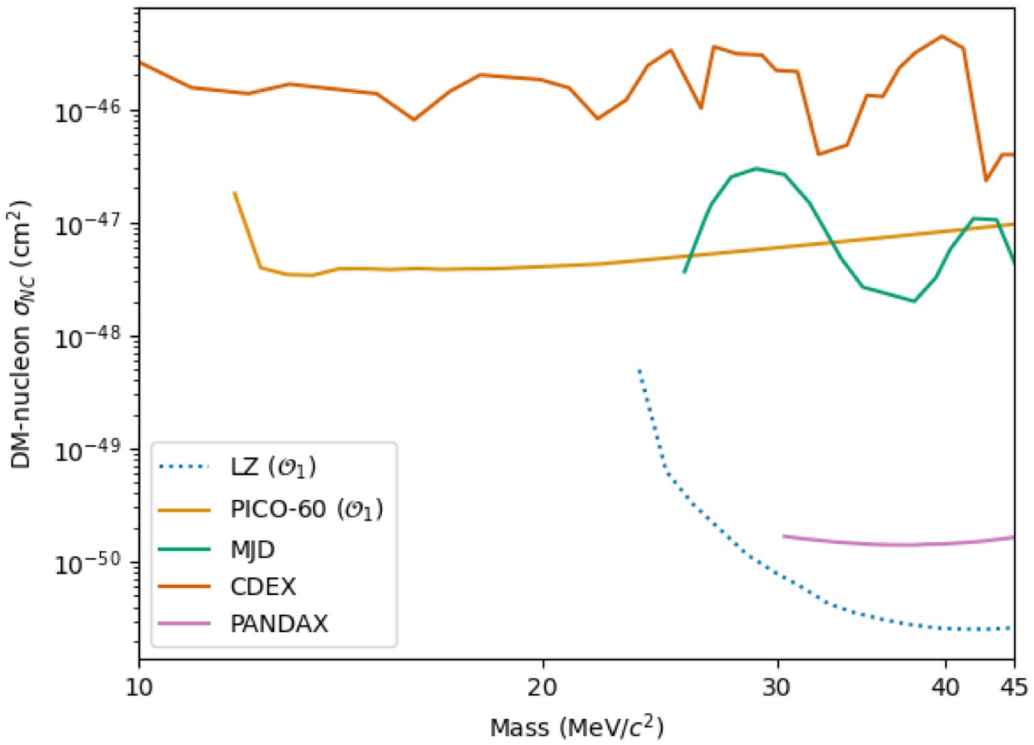

[2504.13089]

R McGehee

Part I

DM turns neutrons into neutrinos

Part II

Neutrons turn DM into neutrinos

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We're thinking about this…

DM turns neutrons into neutrinos

Part II

Neutrons turn DM into neutrinos

R McGehee

We're thinking about this…

DM turns neutrons into neutrinos

People are looking for this!

Neutrons turn DM into neutrinos

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