Gauged Lepton Number and Cosmic-ray Boosted Dark Matter for the XENON1T Excess

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Based on arXiv:2006.13910 [hep-ph]

Collaboration with
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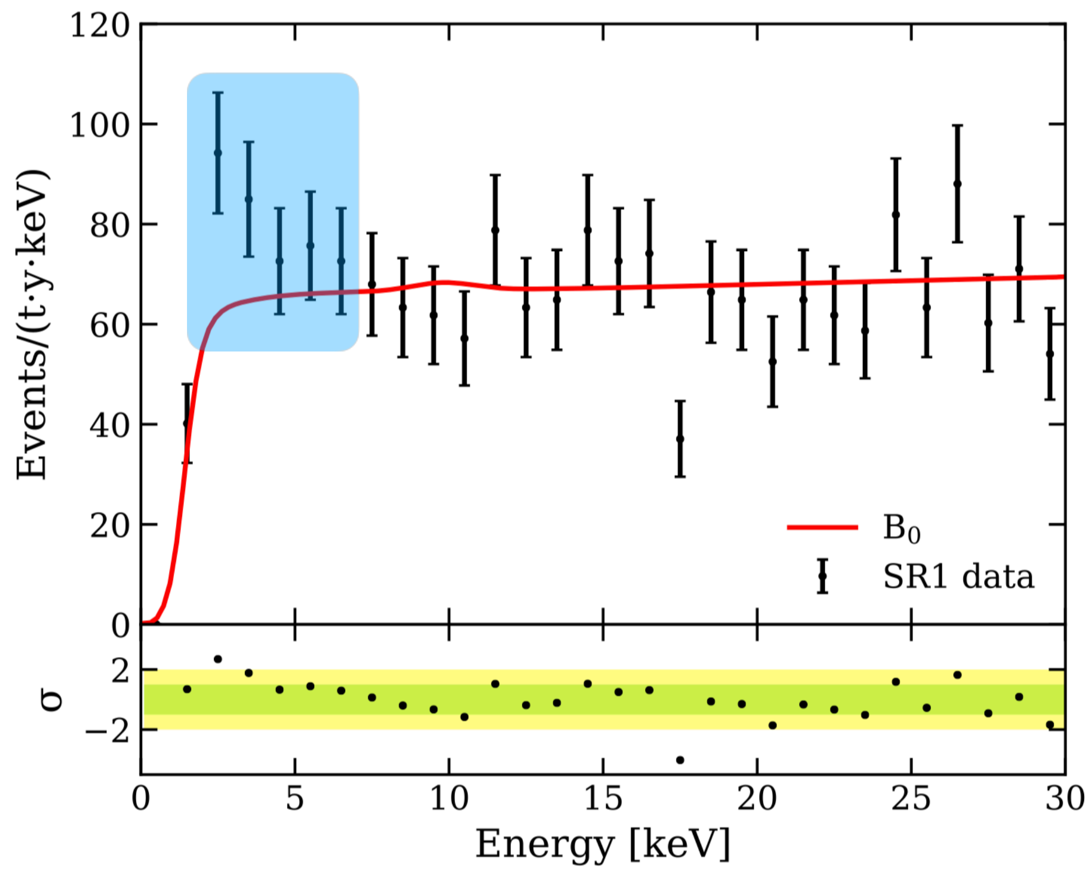
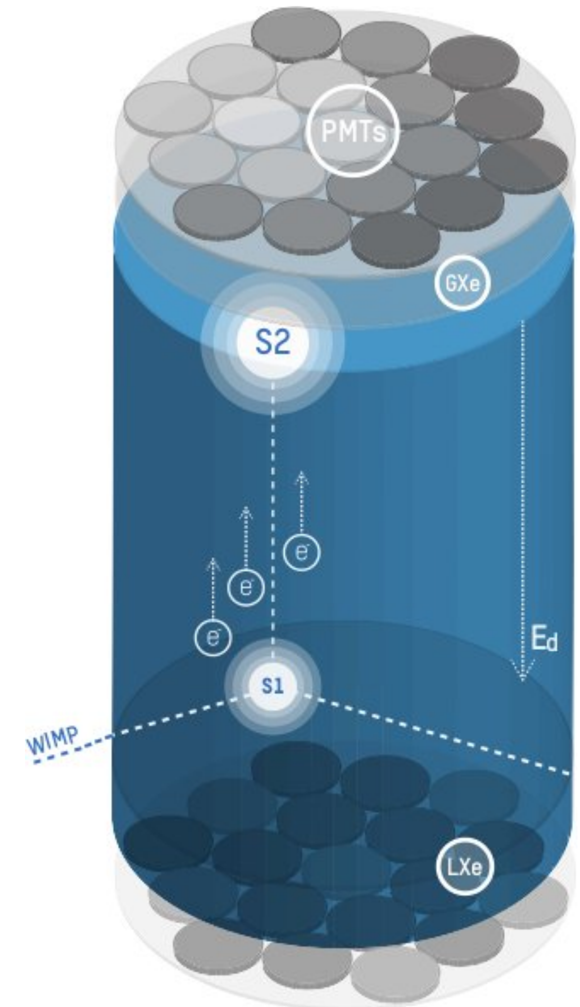
The Excess in the electron recoil spectrum in recent XENON1T result

[2006.09721] [hep-ex]





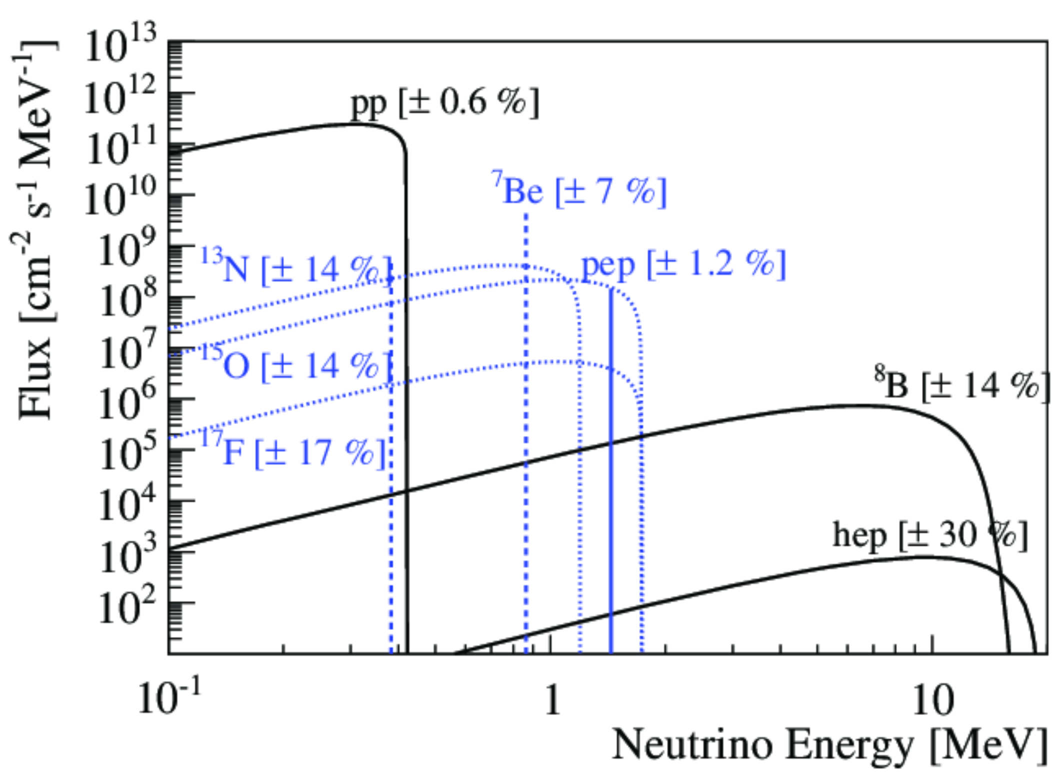
- Report on searches for ER signals with Feb 2017-Feb 2018 (SR1)
- An excess is observed in 1-7 keV
- Backgound = 232 ± 15, Observed = 285 events

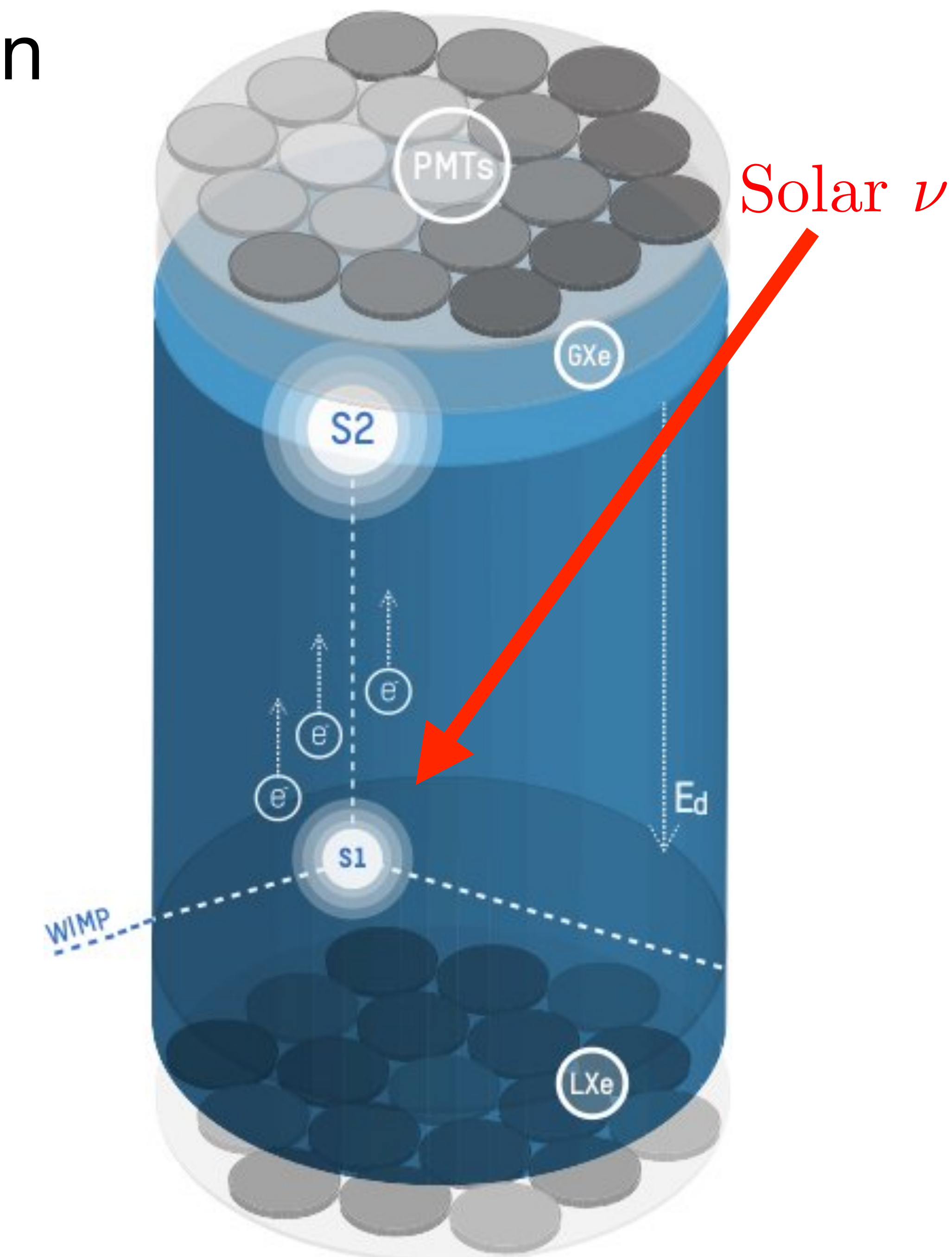
Two Scenarios for Recent XENON1T Excess (I)

R. Harnik et al. [JCAP 07 (2012) 026] [1202.6073] [hep-ph]
C. Boehm et al. [2006.11250] [hep-ph]

- Scenario #1 :
  Consider Non-Standard Interaction between Electron and Neutrinos

$$\underline{\nu_{\text{Solar}}} + e^- \to \nu + e^-$$





Two Scenarios for Recent XENON1T Excess (II)

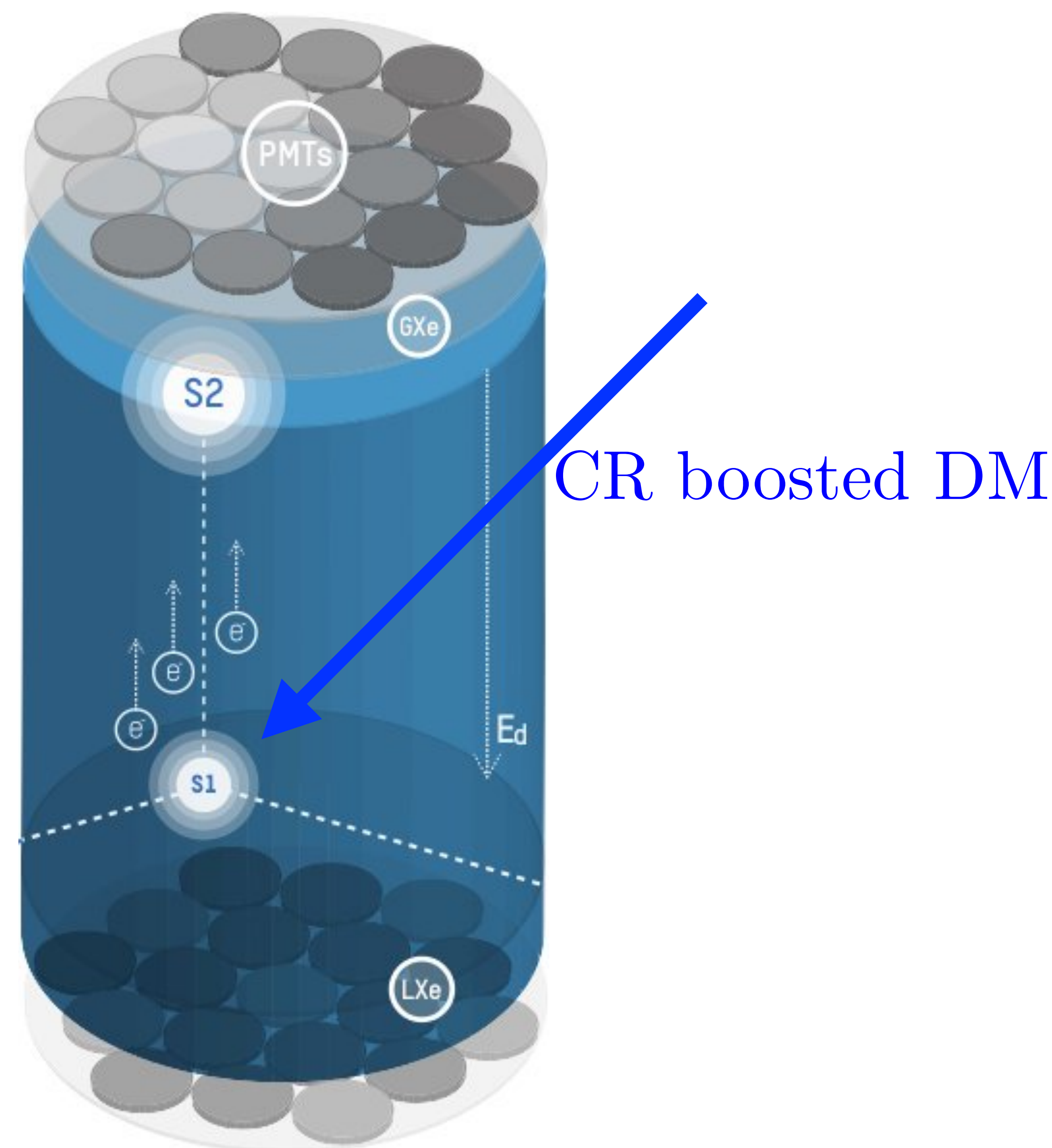
Y. Ema et al. [PRL 122 (2019) 181802] [1811.00520] [hep-ph]

cf) Q.-H. Cao et al. [2006.12767] [hep-ph]

- Scenario #2 :
  Cosmic Ray (electron) Boosted DM interacts with Electrons in detector

$$e^-_{\mathrm{CR}} + \chi_{\mathrm{halo}} \to e^- + \underline{\chi_{\mathrm{Boosted}}}$$

$$\chi_{\mathrm{Boosted}} + e^- \to \chi + e^-$$



Model

$$\mathcal{L} \supset -X_\mu (g_e J_e^\mu + g_\nu J_\nu^\mu + g_\chi J_\chi^\mu) + \ldots$$

$$J_e^\mu = \bar{e}\gamma^\mu e$$
$$J_\nu^\mu = \bar{\nu}_L \gamma^\mu \nu_L$$
$$J_\chi^\mu = \bar{\chi}\gamma^\mu \chi$$

Model (Scenario 1)

Gauged $U(1)_{L_e - L_i}$ $\quad (i = \mu, \tau)$

$$J_e^\mu = \bar{e}\gamma^\mu e$$
$$J_\nu^\mu = \bar{\nu}_L \gamma^\mu \nu_L$$

$$\mathcal{L}_{Scen\#1} \supset -X_\mu (g_e J_e^\mu + g_\nu J_\nu^\mu) + ...$$

$$g_e = g_\nu$$
$$g_\chi = 0$$

- One of simplest extensions of SM
- Free from gauge anomalies
- No additional hadronic interaction

Model (Scenario 2)

Electrophilic mediator to dark sector

$$\mathcal{L}_{Scen\#2} \supset -X_\mu (g_e J_e^\mu + g_\chi J_\chi^\mu) + ...$$

$$J_e^\mu = \bar{e}\gamma^\mu e$$

$$J_\chi^\mu = \bar{\chi}\gamma^\mu \chi$$

$$g_\nu = 0$$

- Electron Cosmic Ray can boost light DM in the halo
- Resulting electron spectrum depends on the mediator and light DM masses m_X, m_χ

XENON1T Electron recoil spectrum in Scenario #1 (NSI)

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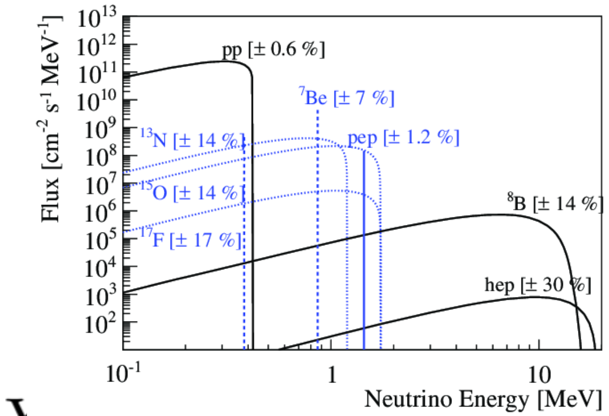


- Electron Recoil spectrum at XENON1T

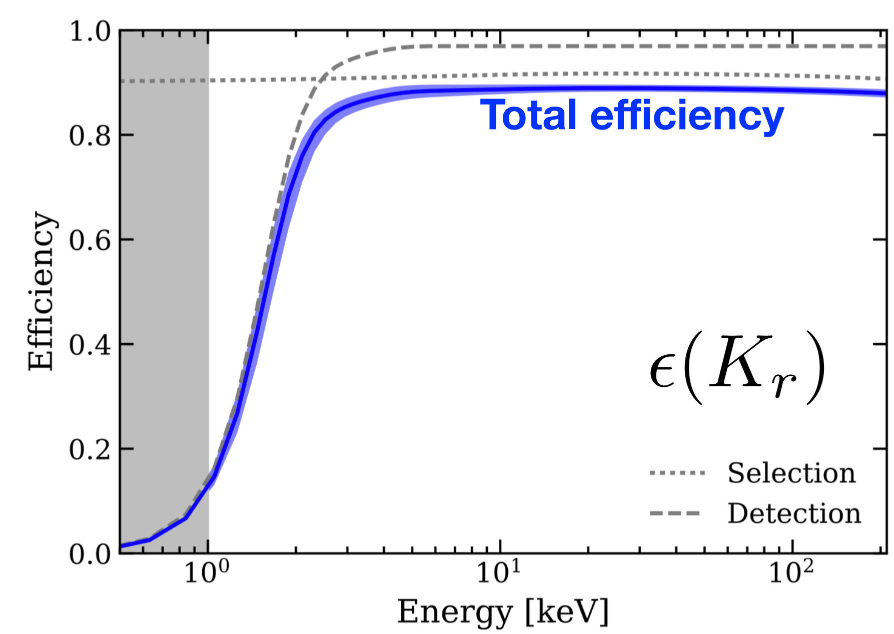
$$\frac{dR^X}{dK_r} = N_T \cdot \epsilon(K_r) \cdot \int_{K_\nu^{\min}(K_r)}^{\infty} \underbrace{\frac{d\Phi_{\text{solar }\nu}}{dK_\nu}}_{\text{Solar } \nu \text{ Flux}} \frac{d\sigma_{\nu e}^{X}}{dK_r} dK_\nu$$

N_T : The (effective) total number of target electrons $4s, 4p, 5s, 5p, 4d$

$\epsilon(K_r)$: The detection efficiency of e^- recoil with recoil energy K_r

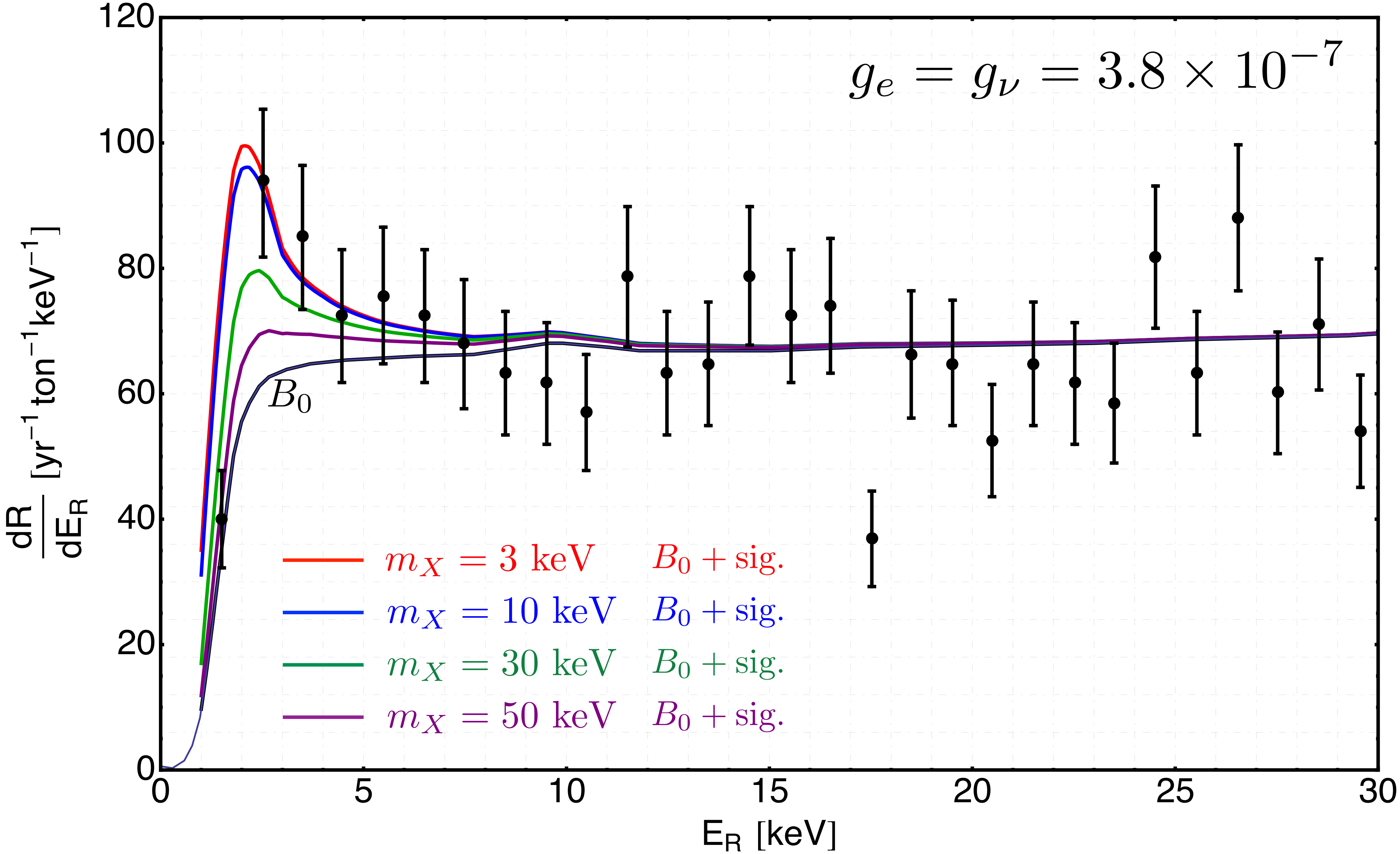
$$\frac{d\sigma_{\nu e}^{X}}{dK_r} = \frac{(g_e g_\nu)^2}{4\pi} \frac{2m_e(m_\nu + K_\nu)^2 - K_e\left((m_\nu + m_e)^2 + 2m_e K_\nu\right) + m_e K_e^2}{(2m_\nu K_\nu + K_\nu^2)(2m_e K_e + m_X^2)^2}$$

$e^-\nu \to e^-\nu$ with t-channel exchange of X boson



XENON1T Electron recoil spectrum in Scenario #1 (NSI)

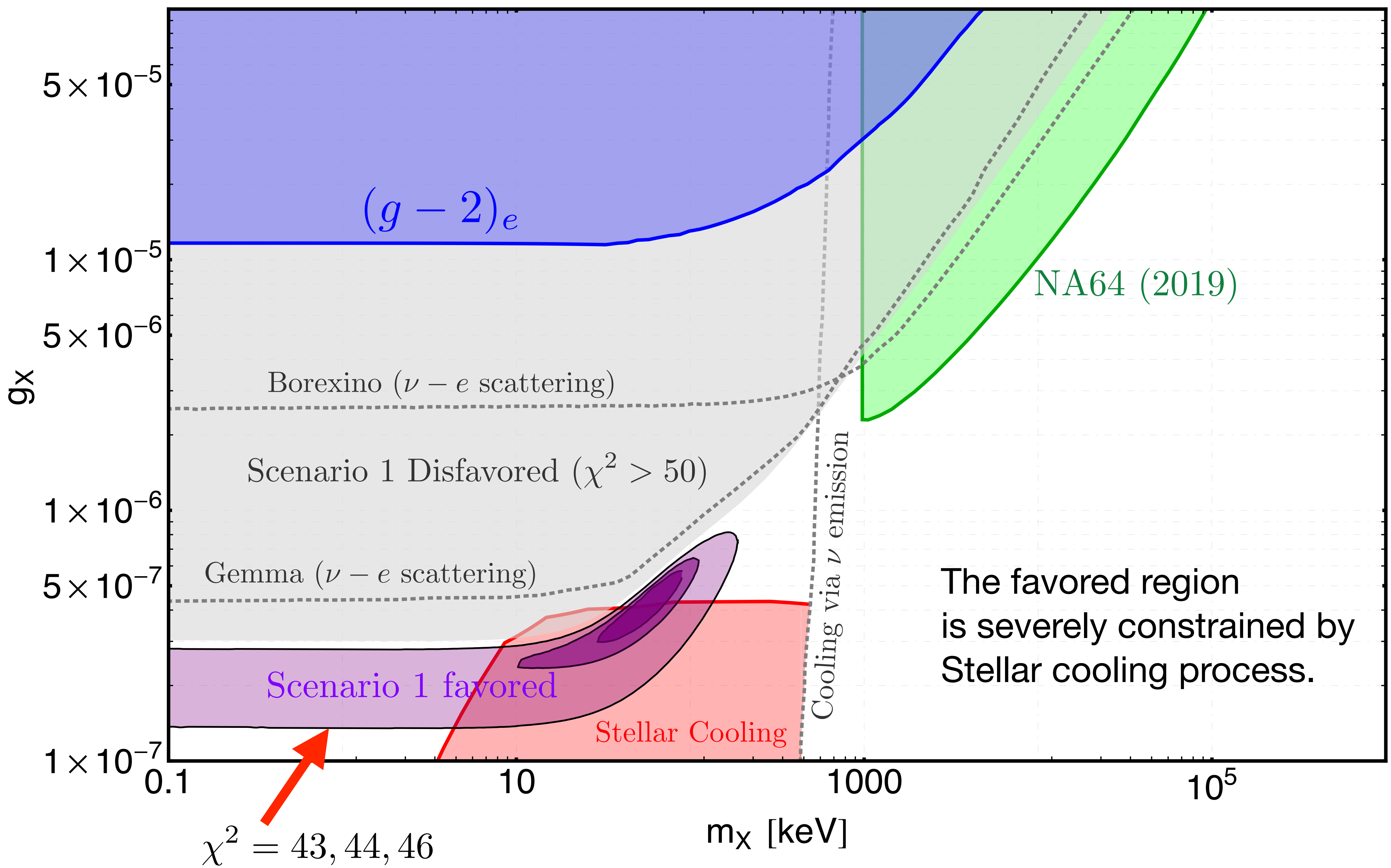
- Light mass ~ O(1-30) keV is preferred for spectral fit



XENON1T Electron recoil spectrum in Scenario #1 (NSI)

- Favored Parameters

YSJ, J.-C. Park, S.-C. Park, P.-Y. Tseng [2006.13910] [hep-ph]



XENON1T Electron recoil spectrum in Scenario #2 (CR boosted DM)

XENON1T Electron recoil spectrum in Scenario #2 (CR boosted DM)

- The flux of DM, boosted by CR electron

$$\frac{d\Phi_{\rm DM}}{d\Omega}(K_{\rm DM}, b, l) = \frac{J(b,l)}{m_{\rm DM}} \int dK_e \underbrace{\frac{d\Phi_e}{d\Omega}}_{\text{electron CR flux}} \underbrace{\frac{d\sigma_{{\rm DM}e \to {\rm DM}e}}{dK_{\rm DM}}}_{e^-_{\rm CR} + \chi_{\rm halo} \to e^- + \chi_{\rm Boosted}}$$

$$J(b,l) = \int_{l.o.s} d\ell \rho_{\rm DM}$$

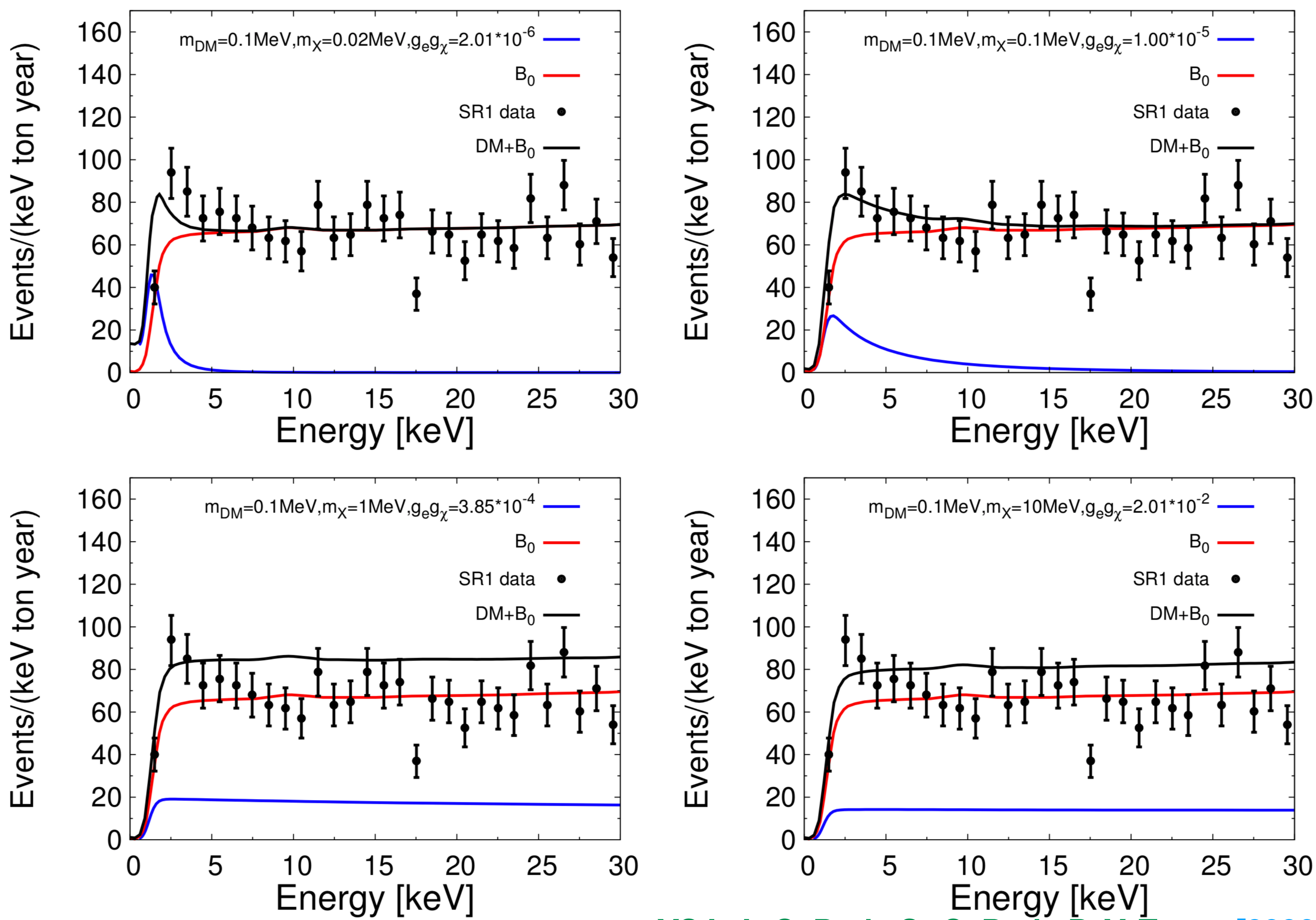
- Boosted DM-electron (in the detector) cross section with light mediator X

$$\frac{d\sigma_X({\rm DM}e \to {\rm DM}e)}{dK_e} = \frac{(g_e g_\chi)^2}{4\pi} \frac{2m_e(m_{\rm DM}+K_{\rm DM})^2 - K_e\left((m_e+m_{\rm DM})^2 + 2m_e K_{\rm DM}\right) + m_e K_e^2}{(2m_{\rm DM}K_{\rm DM} + K_{\rm DM}^2)(2m_e K_e + m_X^2)^2}$$

XENON1T Electron recoil spectrum in Scenario #2 (CR boosted DM)

- Mediator mass dependence

Light mediator mass is preferred



YSJ, J.-C. Park, S.-C. Park, P.-Y. Tseng [2006.13910] [hep-ph]

XENON1T Electron recoil spectrum in Scenario #2 (CR boosted DM)

- Light DM mass dependence

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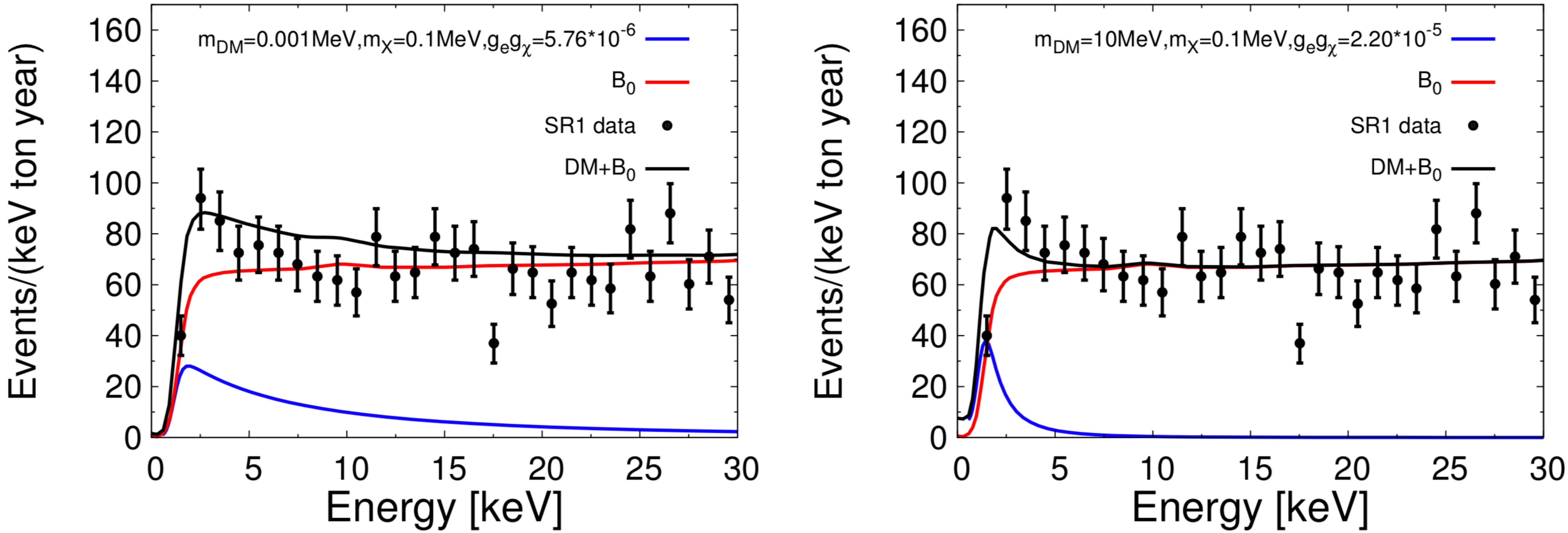
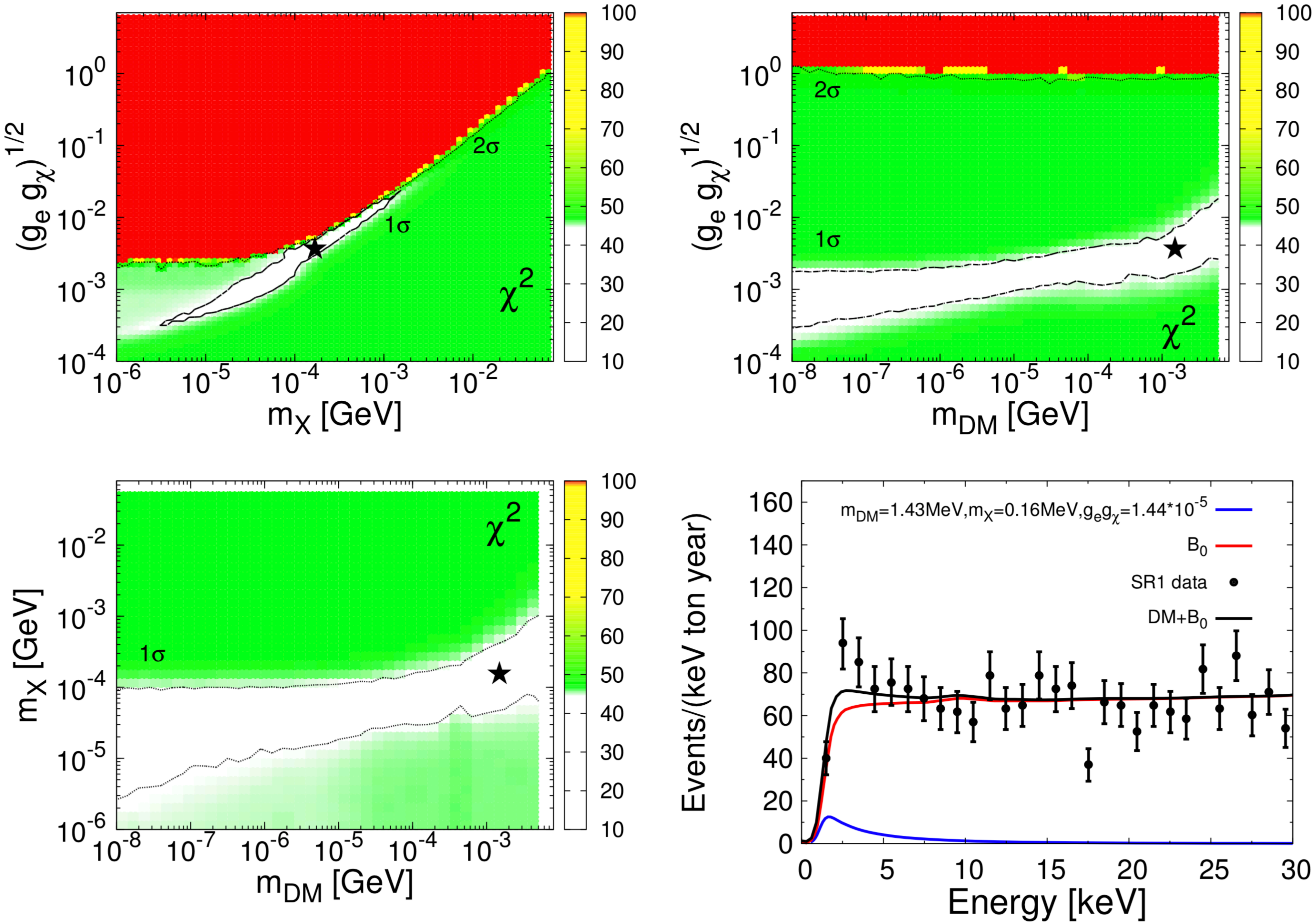


Not so sensitive to DM mass.

XENON1T Electron recoil spectrum in Scenario #2 (CR boosted DM)

YSJ, J.-C. Park, S.-C. Park, P.-Y. Tseng [2006.13910] [hep-ph]

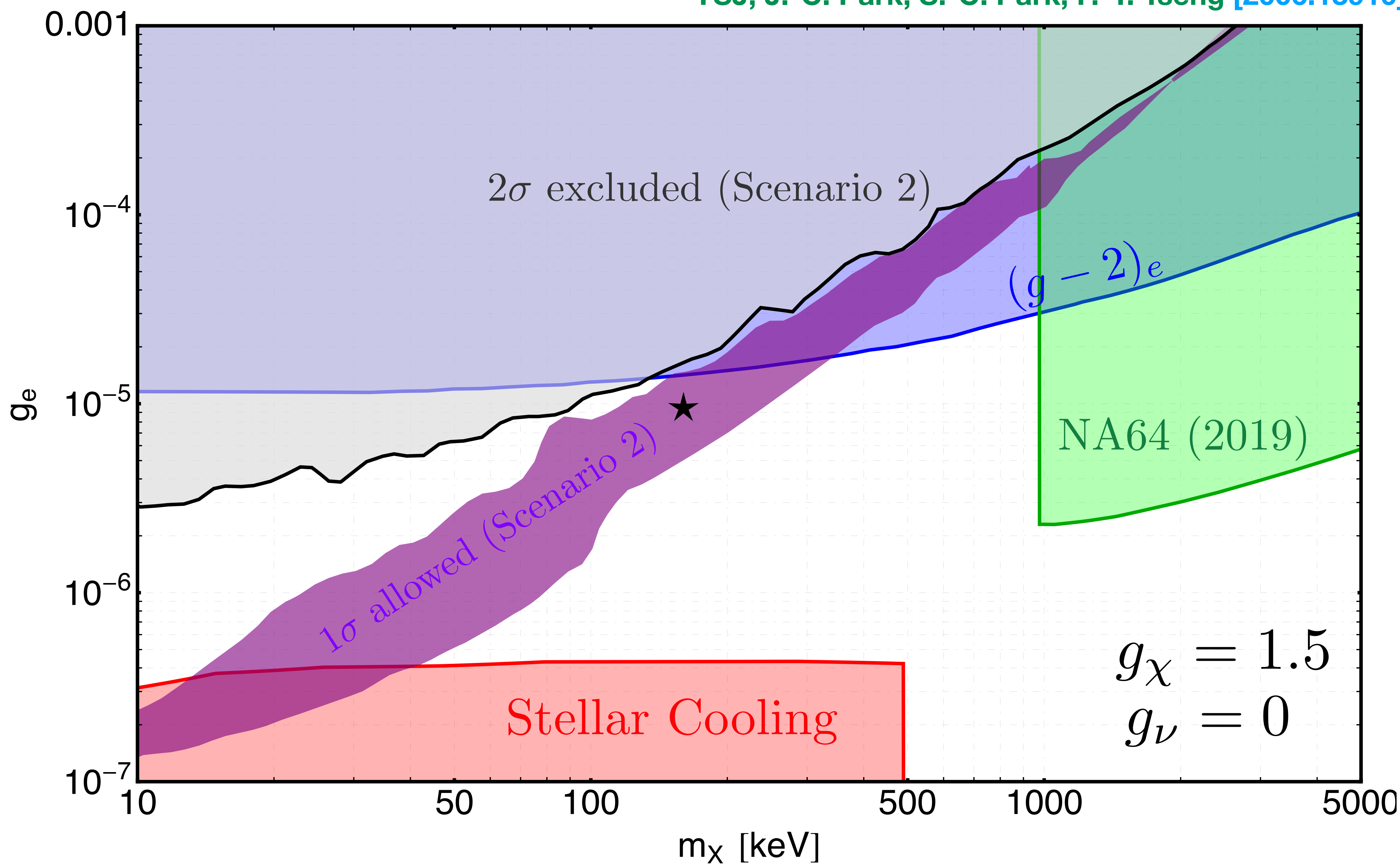
- Favored parameters in Scenario #2



XENON1T Electron recoil spectrum in Scenario #2 (CR boosted DM)

- Constraints (mediator mass/coupling) on Scenario #2

YSJ, J.-C. Park, S.-C. Park, P.-Y. Tseng [2006.13910] [hep-ph]



cf) Future probe of Scenario #2 (CR boosted DM)

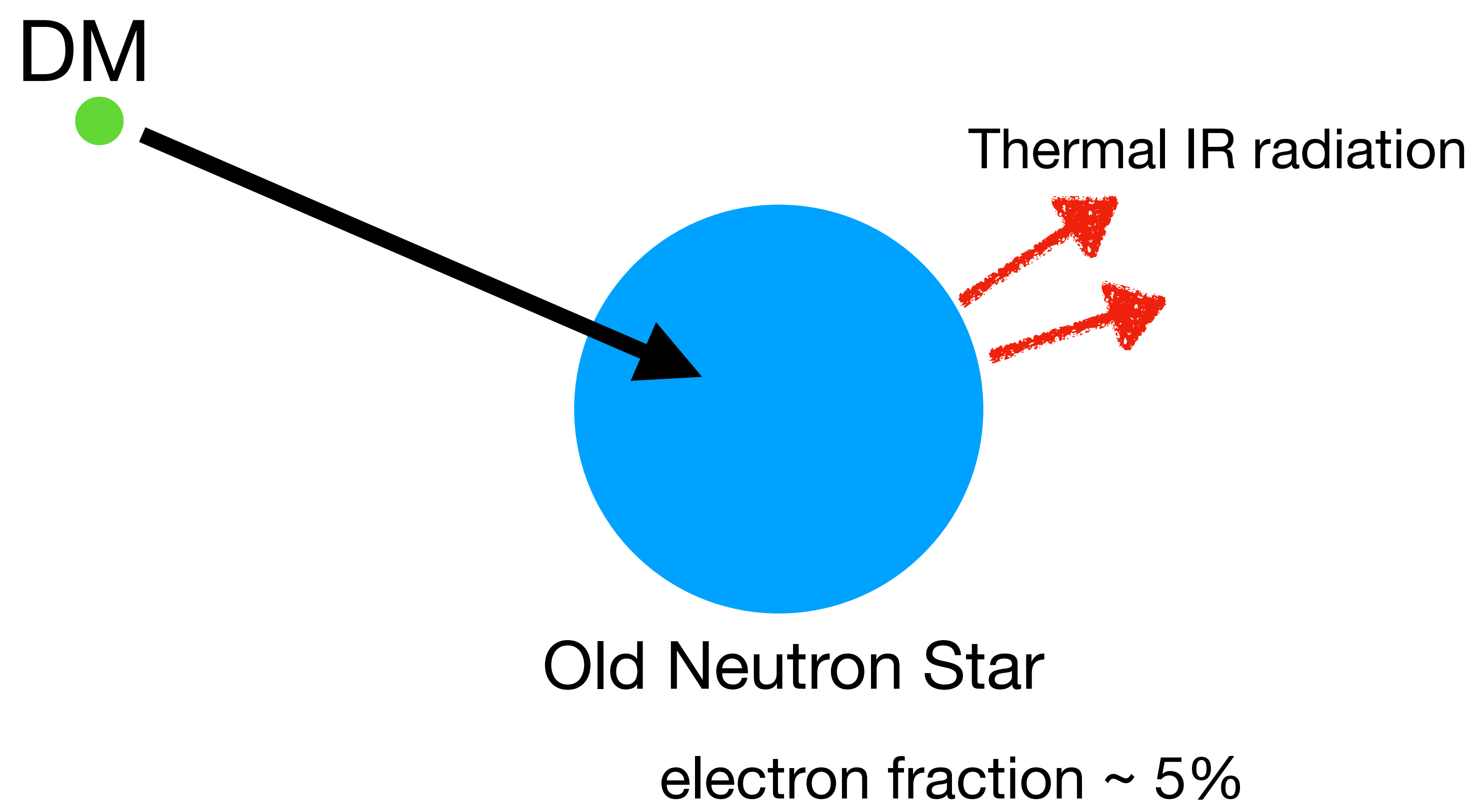
- Neutron Star Heating by DM capture (up to 1500K)

$$C_c \simeq 9.5 \times 10^{37}\ \mathrm{sec}^{-1}$$

for the best-fit parameters

$$C|_{\mathrm{geom}} \simeq 1.6 \times 10^{28}\ \mathrm{sec}^{-1}$$

Geometric limit of capture rate



- Future Search using James Webb Infrared Telescope can be a sensitive probe of Scenario #2.

Conclusion

- We consider Gauged Lepton Number and Electrophilic gauge mediator models as the intriguing interpretations of recent XENON1T electron recoil spectrum Excess.

- In Scenario 1, light mass ~O(1-30) keV and small coupling O(10^{-7}) provides good spectral fit to the XENON1T ER spectrum, although the stellar cooling by neutrino emission can constrain the favored parameters.

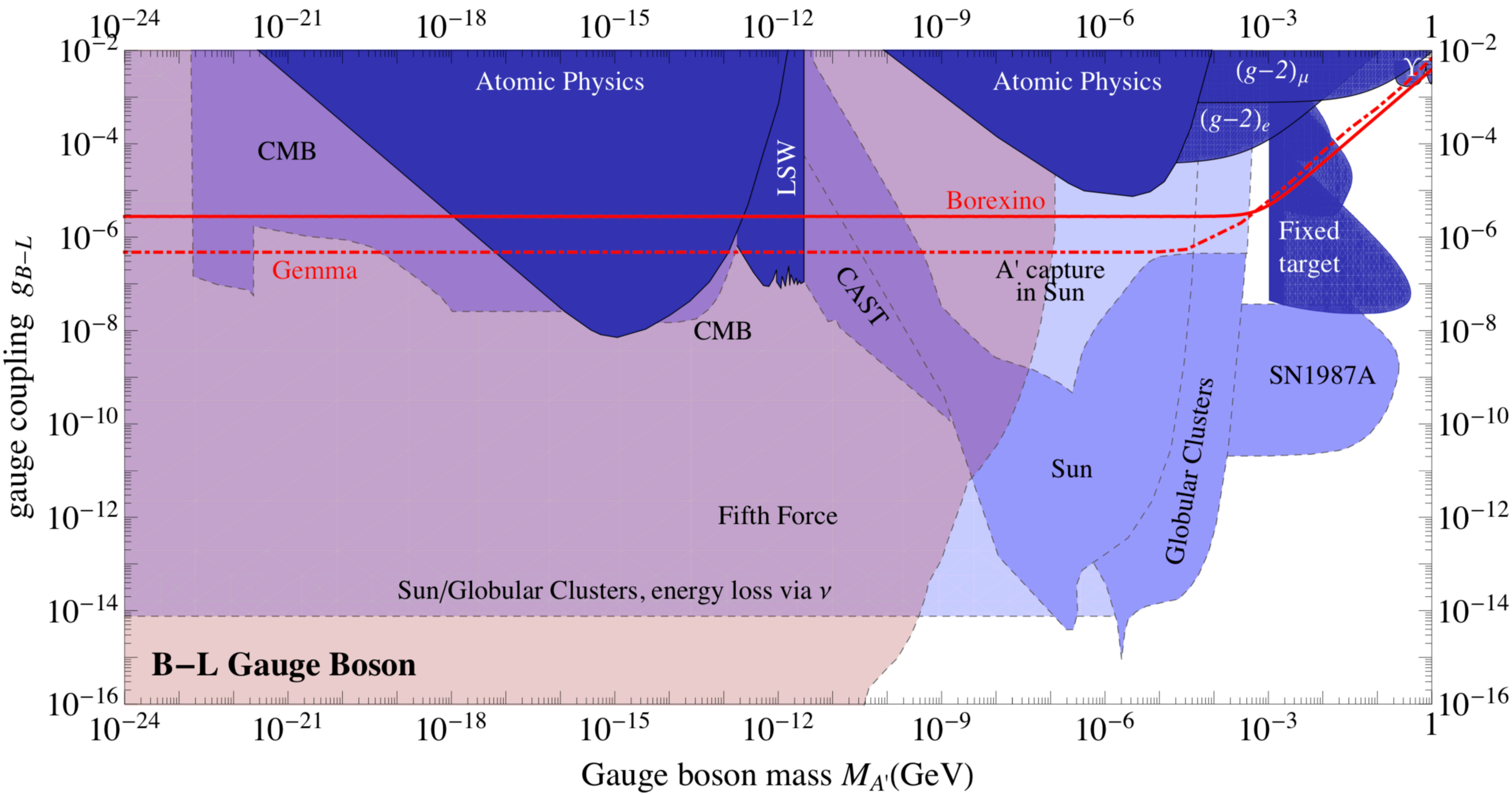
- In Scenario 2, the CR-electron boosted DM can scatter with target electrons in XENON1T detector, and generally O(10-100) keV mediator mass, 1 keV - 50 MeV of DM mass provide a good fit to the excess.

Thank you for your attention

backup slides

Constraints on light mediator

R. Harnik et al. [JCAP 07 (2012) 026] [1202.6073] [hep-ph]



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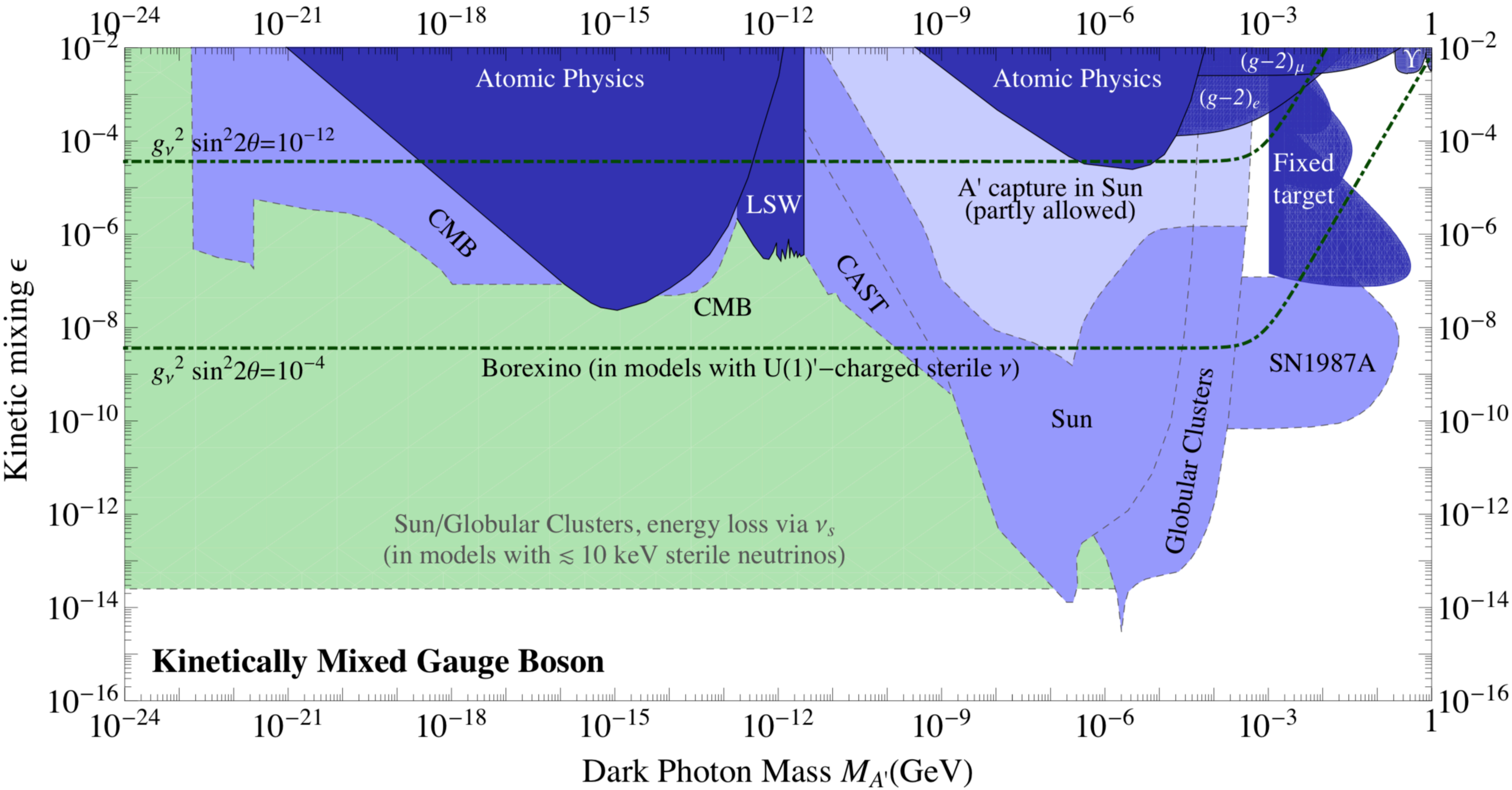

CR electron flux (2 MeV - 90 GeV)