

PBH AS COSMIC ACCELERATOR OF LIGHT DM

SK JEESUN

TDLI, SHANGHAI, CHINA



**2ND NEW HORIZONS FOR PSI WORKSHOP
@ ICTP-AP, BEIJING, 2026**



Based on: JCAP 06 (2026) 063

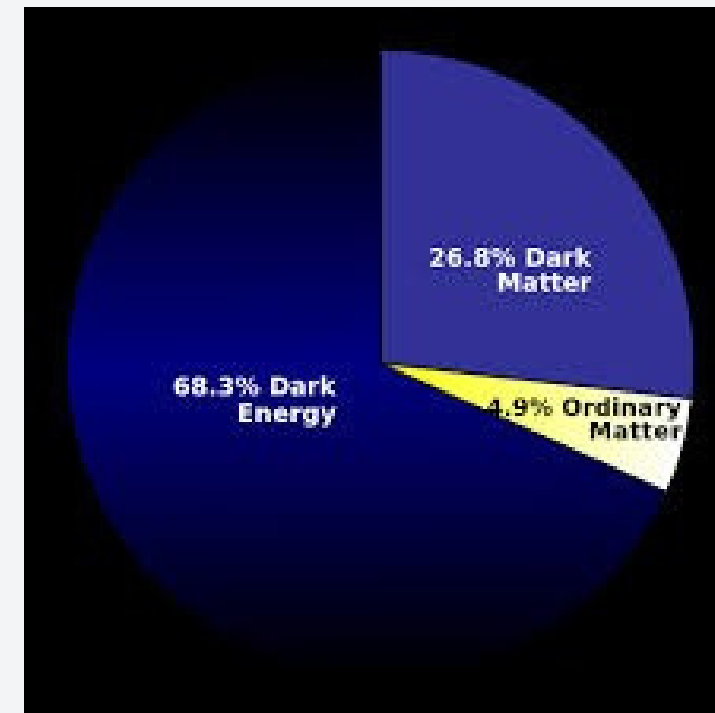
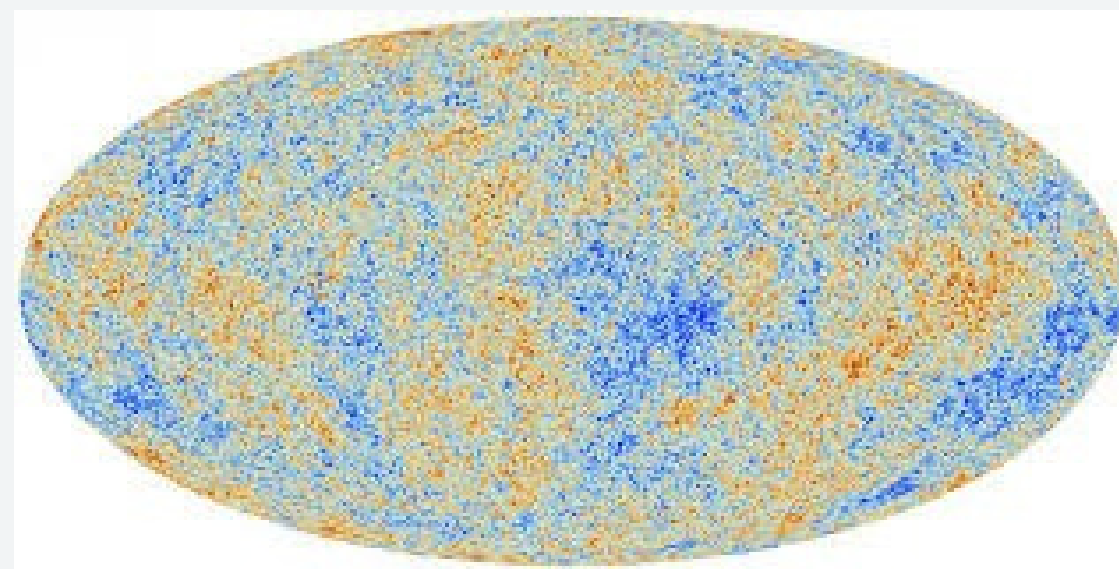
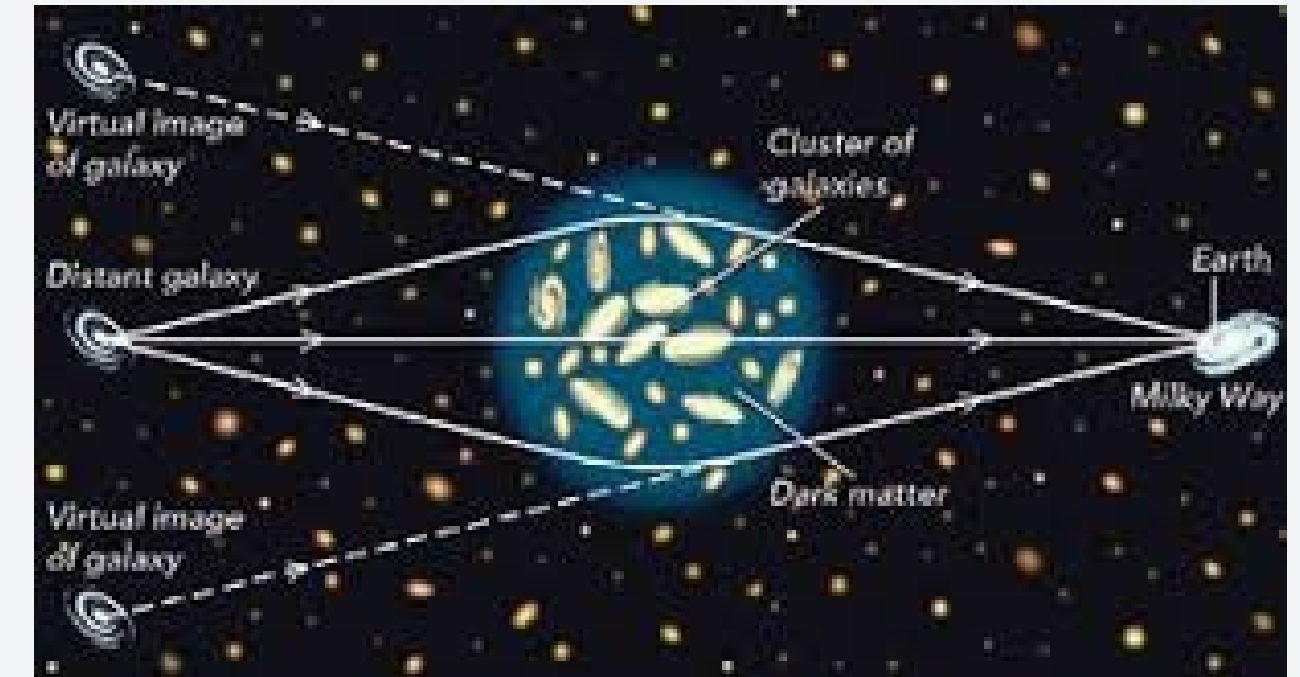
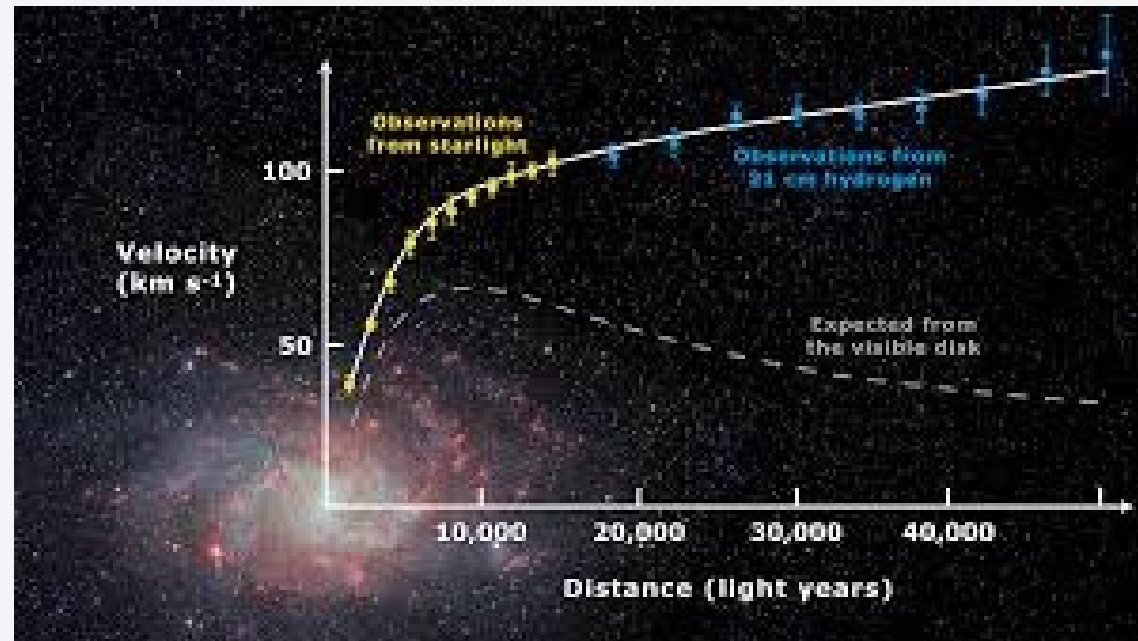
SJ, Anirban Majumdar, Rahul Srivastava

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Outline

- Motivation
- PBH evaporated DM: Why?
- Detection of PBH evaporated DM: How?
- Results
- Conclusion

Evidence of Dark matter



- Strongly suggest ~25% non-luminous, non baryonic DM
- SM fails to explain : begs for an extension

V.Rubin, WMAP, Planck 2018,
M.Lisanti 2016

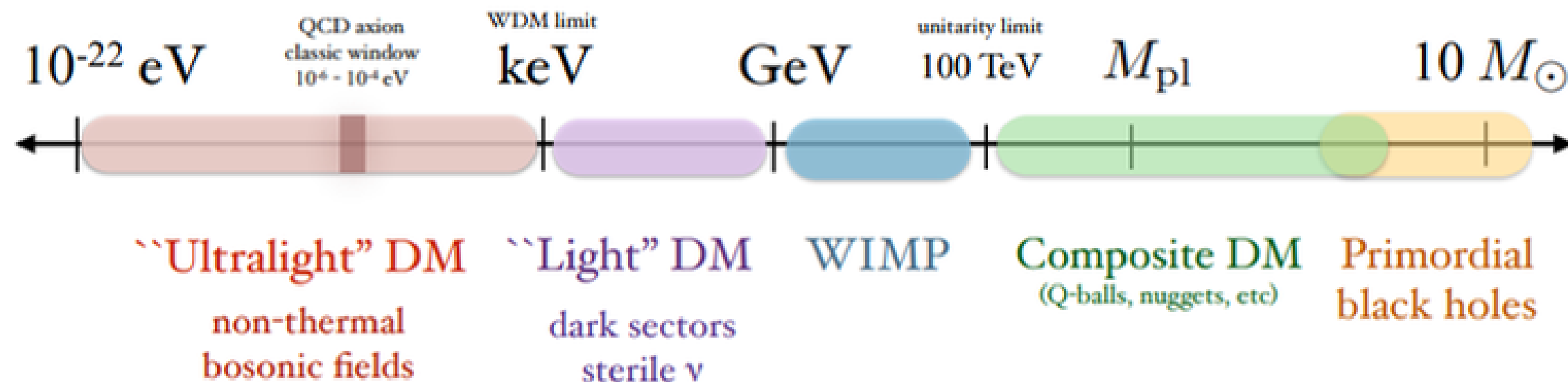
The puzzle of particle Dark matter

What we know:

- Interacts gravitationally
- Non luminous, electric charge very small
- Cold with $\text{mass} \ll \text{momentum}$
- Collisionless at large scale

What we don't know:

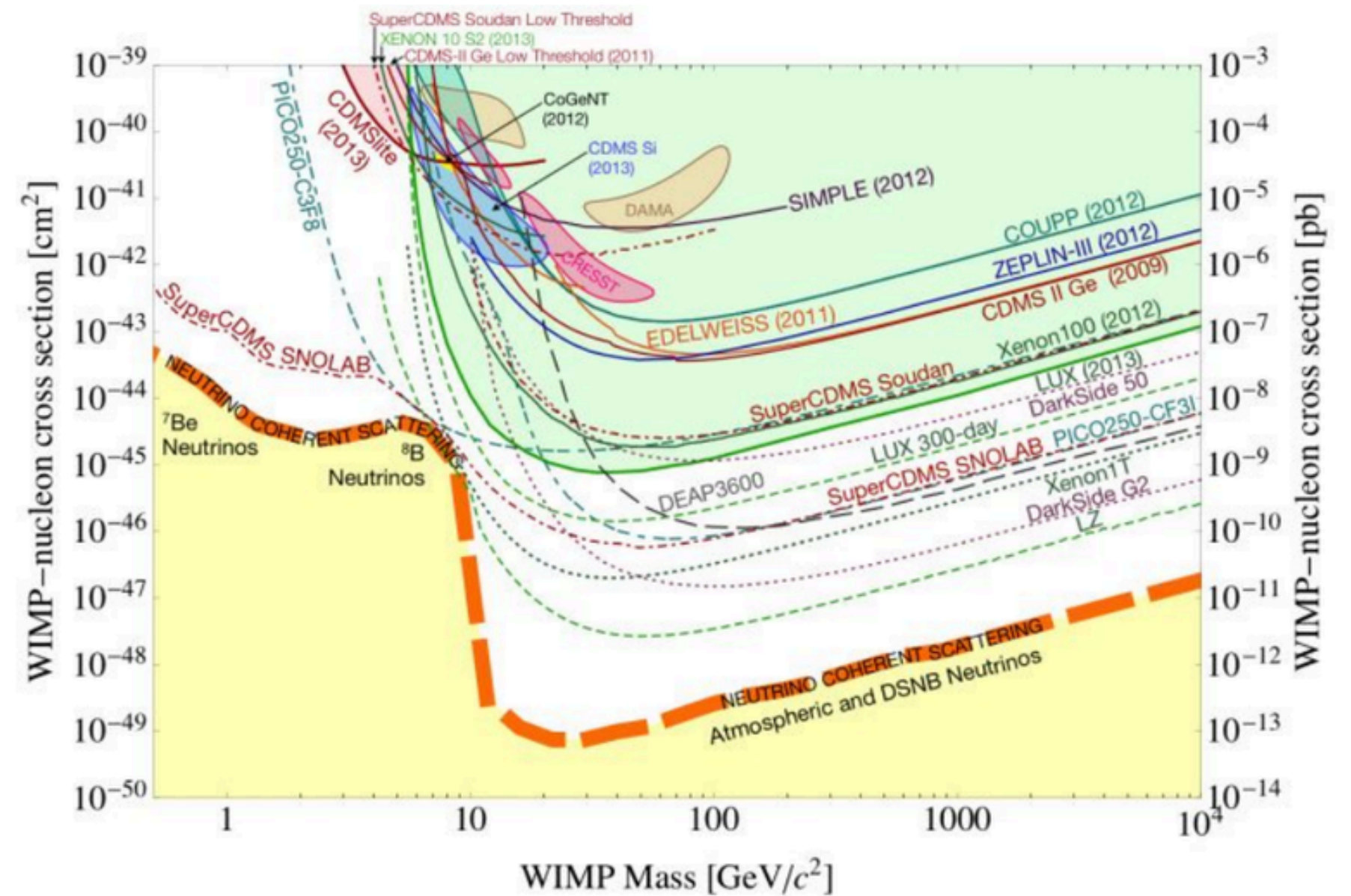
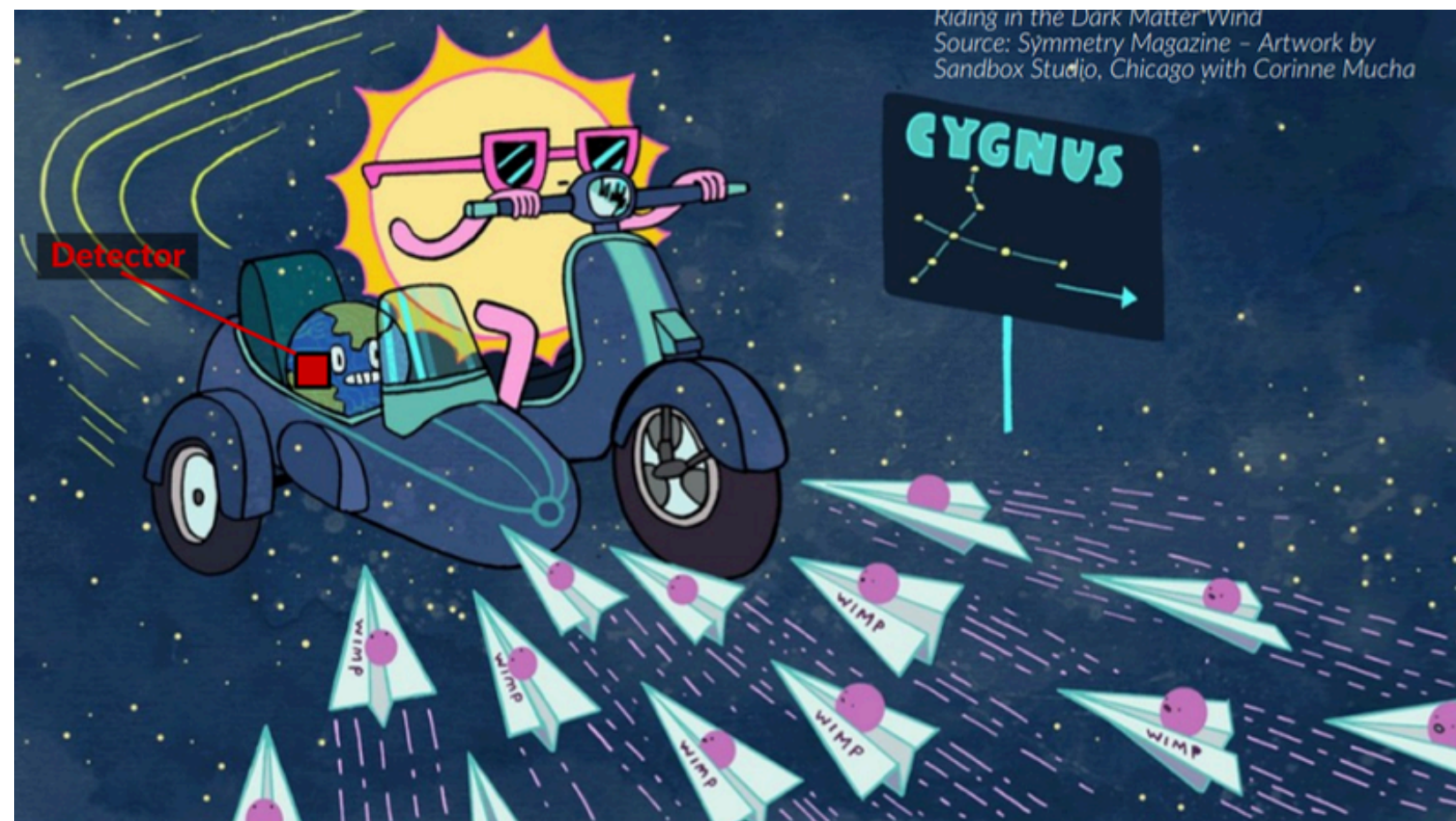
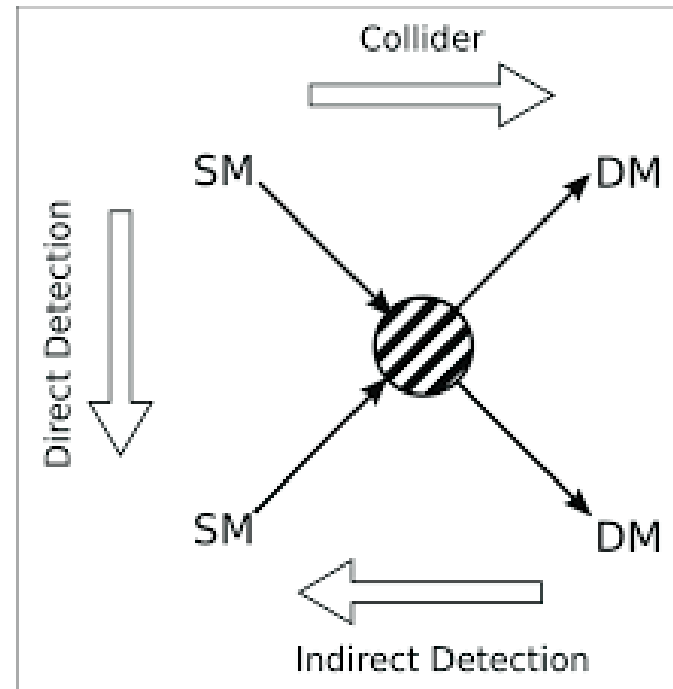
- Compact object or fundamental particle?
- Mass, Spin?
- interaction (with SM) other than Gravitational



- Mass spanning from $1\text{e-}22$ eV to the mass of least massive DM galaxy

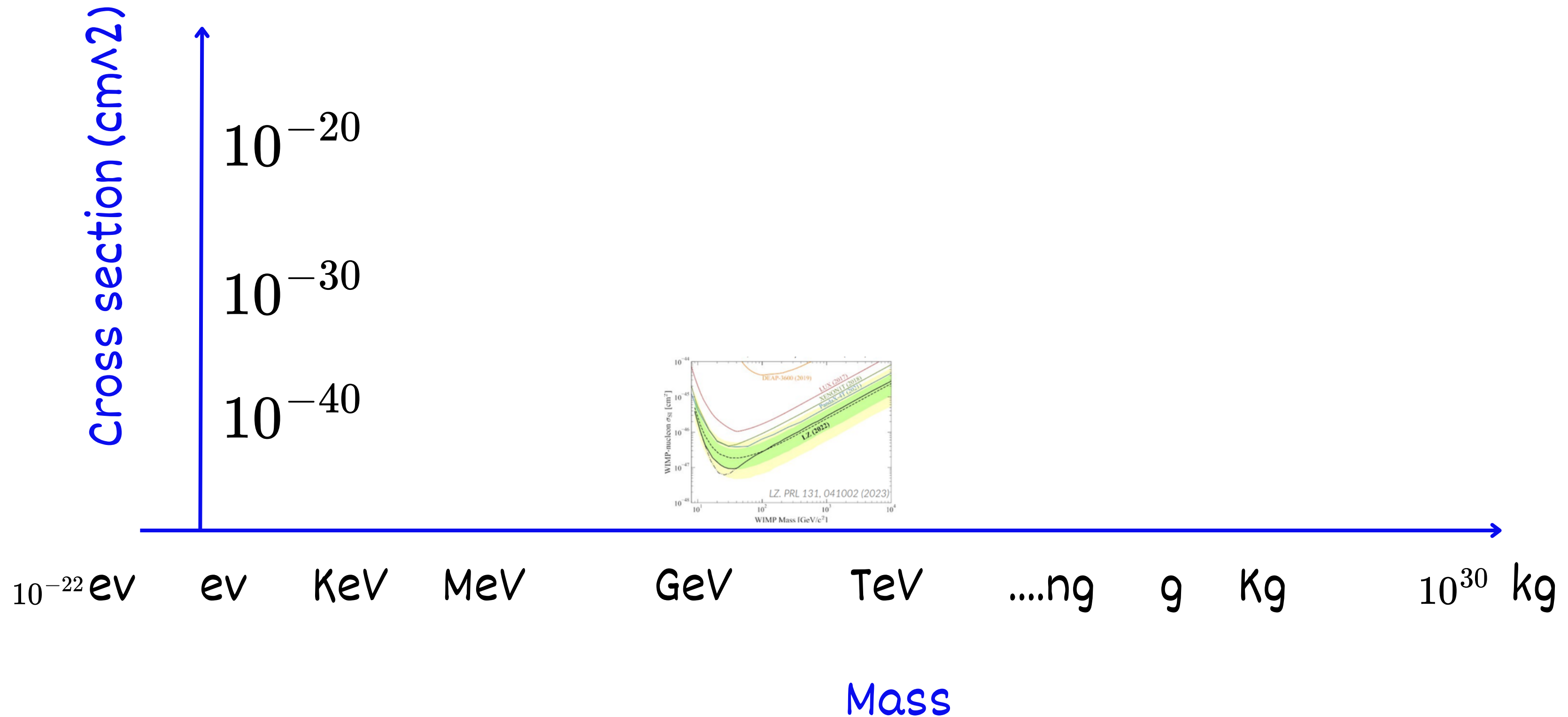
M.Lisanti 2016, T. Lin
2019, Cirelli et al 2024

Directly detecting Dark matter

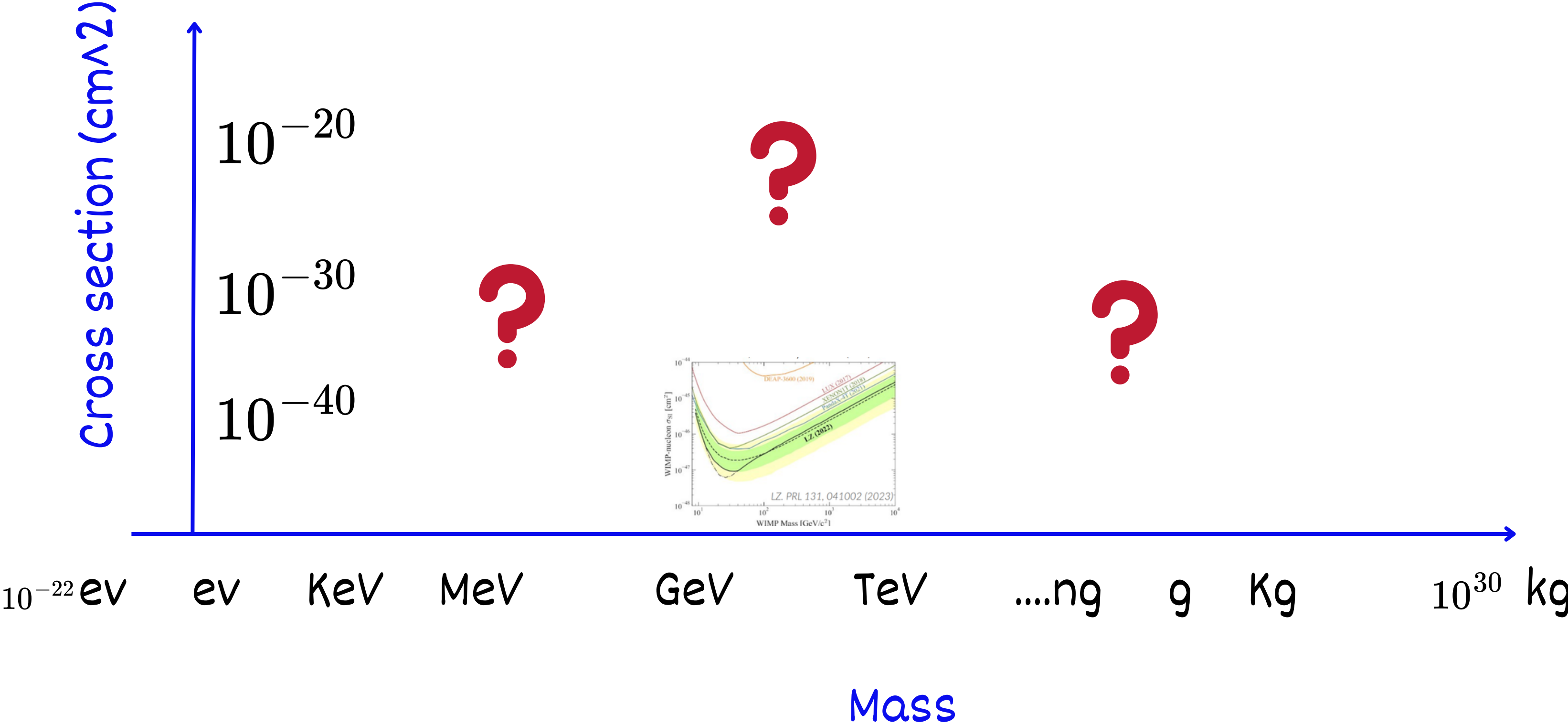


Pushing towards neutrino floor
at GeV scale

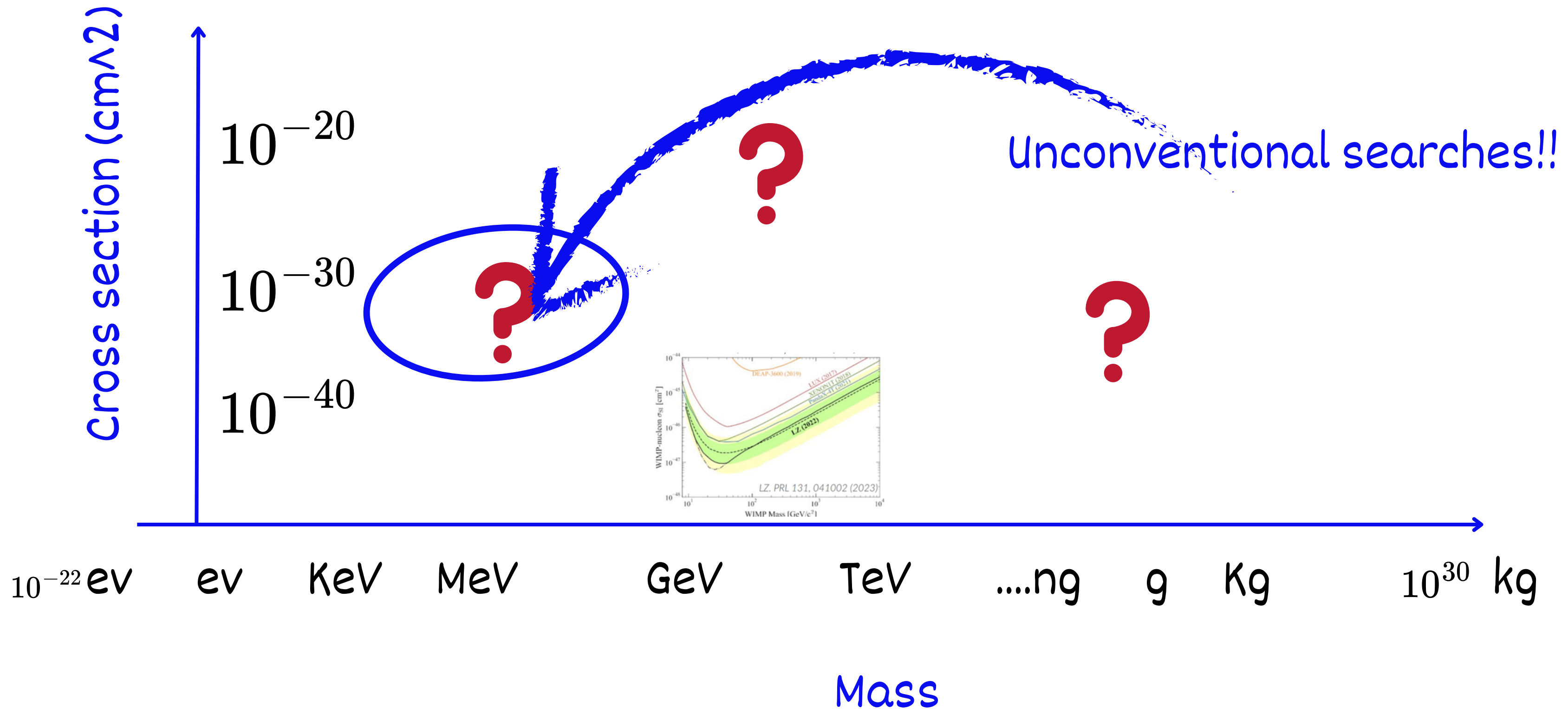
Hunting Dark matter from direct search



Hunting Dark matter



Hunting Dark matter



Hunting Sub-GeV Dark matter

- Event rate $\chi + N \rightarrow \chi + N$

$$\frac{dR}{dE_R} = N_T \frac{\rho_\chi}{M_\chi} \int_{v_{min}}^{\infty} d^3v \frac{d\sigma_{\chi N}}{dE_R} v f(\vec{v})$$

- Ton size detector with huge $N_T \sim 10^{27}$ to probe very low cross-section
- But what about the low mass ($< \text{GeV}$)?
- Minimum velocity required to generate recoil

$$v_{min} = \sqrt{\frac{m_N E_R}{2\mu_{\chi N}^2}}$$
$$M_\chi \sim 100 \text{ MeV}, E_R = 1 \text{ keV},$$
$$v_{min} = 10^{-2} c$$

- DM too slow to have K.E. sufficient to generate E_R^{th} following standard MB dist.

$$f(v) = \frac{1}{N_0} \exp\left(-\frac{v^2}{v_0^2}\right) \Theta(v_{esc} - |v|)$$

$$v_0 \approx 230 \text{ km/s} (10^{-3} c), v_{esc} \approx 600 \text{ km/s}$$

- Low momentum/kinetic energy ---> main challenge to detect light DM

Hunting Sub-GeV DM

Hunting Sub-GeV DM

- Lighter Target

Electron recoil
experiments in
Xenon, LZ, Sensei
etc.

Can't probe below MeV

Hunting Sub-GeV DM

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Electron recoil
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- Accelerating DM
to higher velocities



Hunting Sub-GeV DM

- Lighter Target

Electron recoil experiments in Xenon, LZ, Sensei etc.

- Accelerating DM to higher velocities

Boosted DM:

1. Cosmic p, e scattering
2. Solar reflection
3. Multicomponent
4. DSNB etc.

Bringman et al PRL 2019

An et al PRD 2021

Das et al JCAP 2024

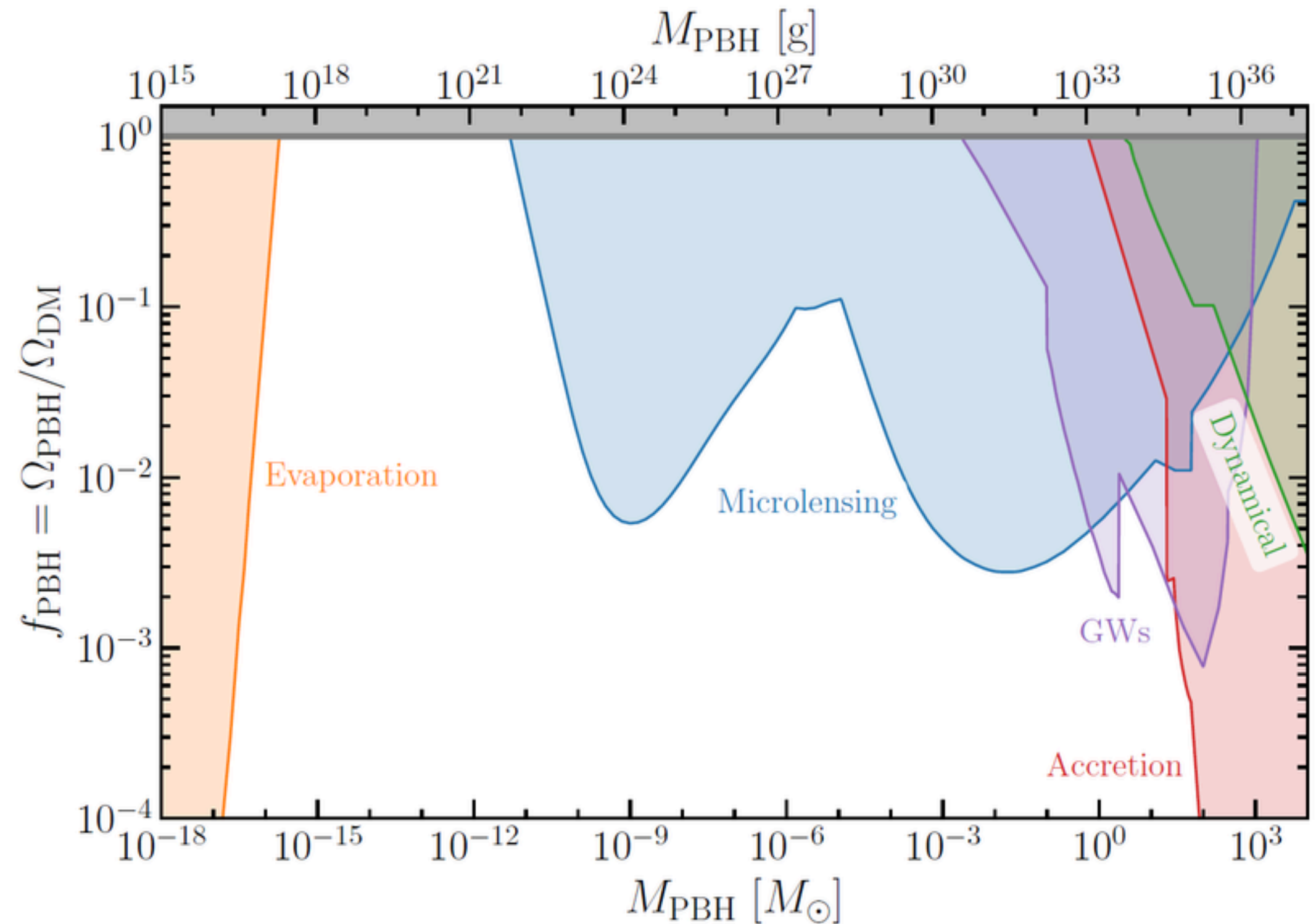
PBH: a cosmic accelerator

- Primordial black holes (PBH) : collapse of large density inhomogeneities in the early universe
- Expected to evaporate via Hawking radiation

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- Can be DM candidate: strong constraints
- PBH can emit particles irrespective of their interaction strength

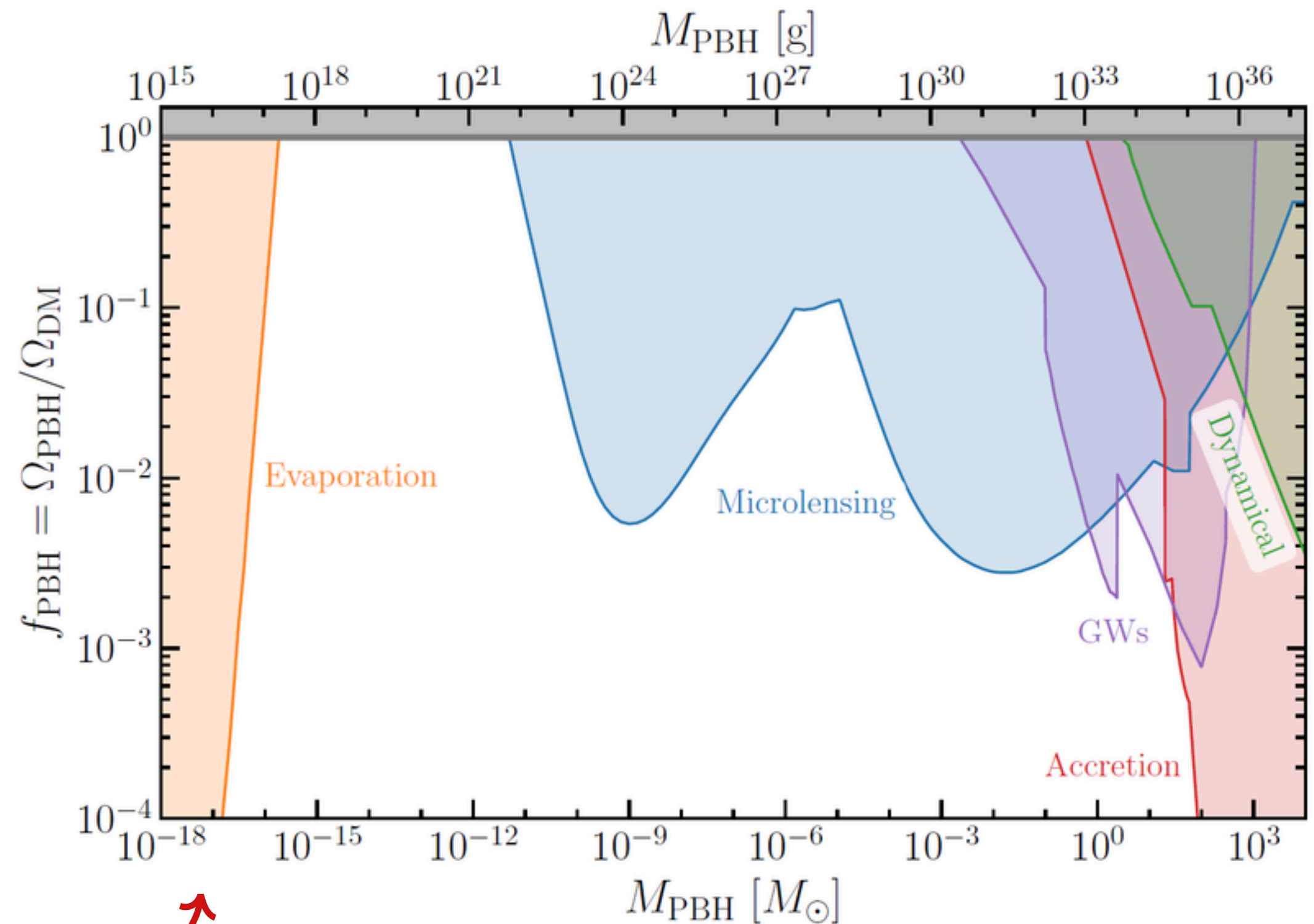
$$T_{\text{PBH}} = \frac{\hbar c^3}{8\pi G M_{\text{PBH}} k_B} \approx 10^{-7} \left(\frac{M_{\text{PBH}}}{M_{\odot}} \right)^{-1} \text{ K},$$



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Dark particle from PBH

Galactic flux :

$$\frac{d^2\Phi_{\chi}^{\text{MW}}}{dT_{\chi} d\Omega} = D_{\text{halo}} \frac{f_{\text{PBH}}}{4\pi M_{\text{PBH}}} \left. \frac{d^2 N_{\chi}}{dT_{\chi} dt} \right|_{t=t_{\text{univ}}} .$$

$$D_{\text{halo}} = \int_{\Delta\Omega} \frac{d\Omega}{4\pi} \int_0^{\ell_{\text{max}}} \underbrace{\rho_{\text{MW}}[r(\ell, \psi)]}_{\text{NFW}} d\ell$$

Extragalactic flux :

$$\frac{d^2\Phi_{\chi}^{\text{EG}}}{dT_{\chi} d\Omega} = \frac{f_{\text{PBH}} \rho_{\text{DM}}}{4\pi M_{\text{PBH}}} \int_{t_{\text{min}}}^{t_{\text{max}}} dt [1 + z(t)] \left. \frac{d^2 N_{\chi}}{dT_{\chi} dt} \right|_{E_{\chi}^s}$$

$$\rho_{\text{DM}} = 2.3 \times 10^{-30} \text{ g cm}^{-3}$$

BLACKHAWK v2.3

Dark particle from PBH

Galactic flux :

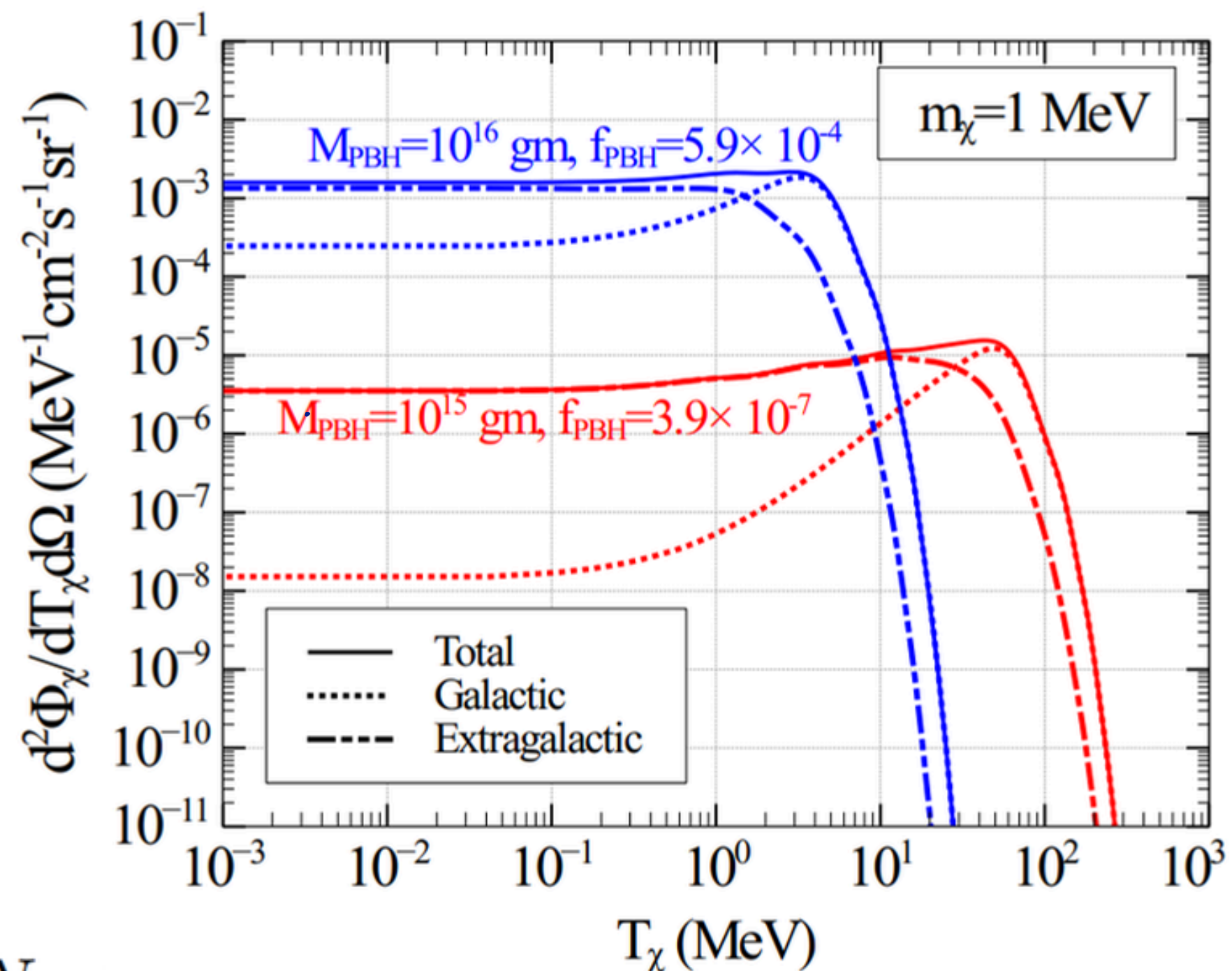
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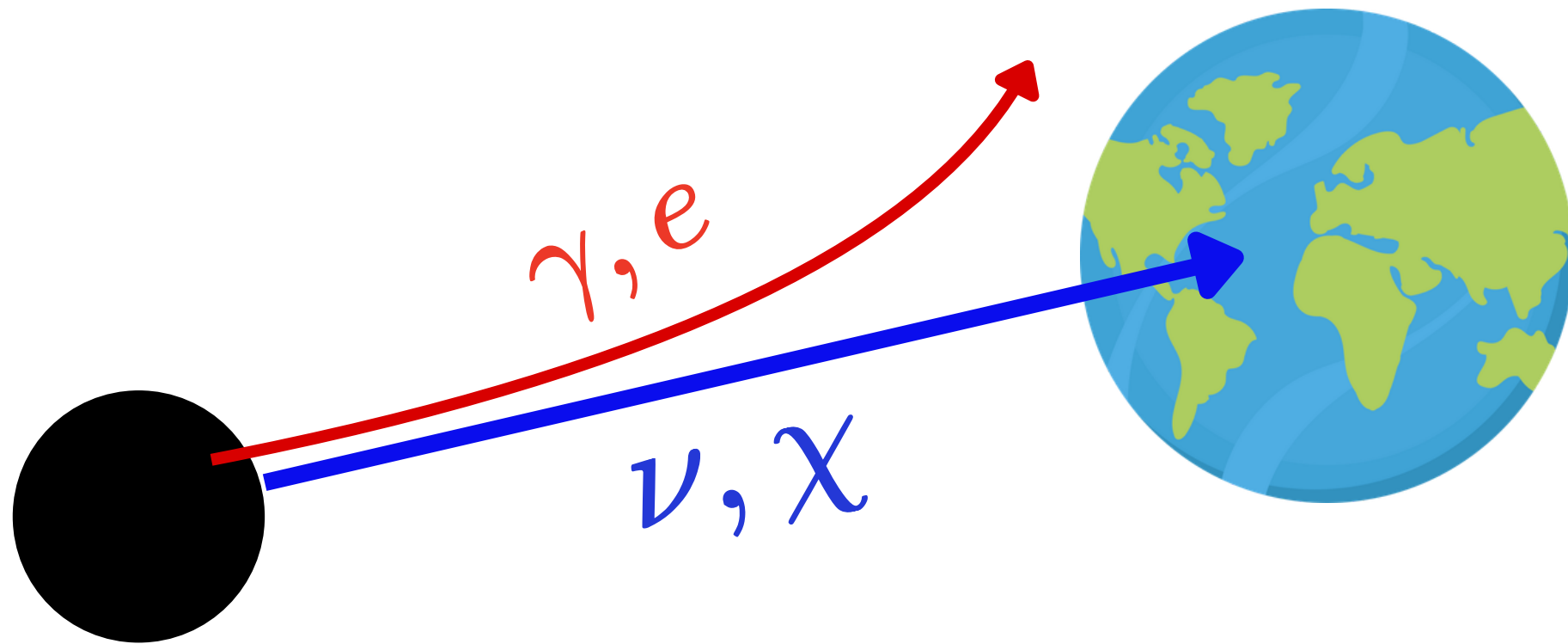
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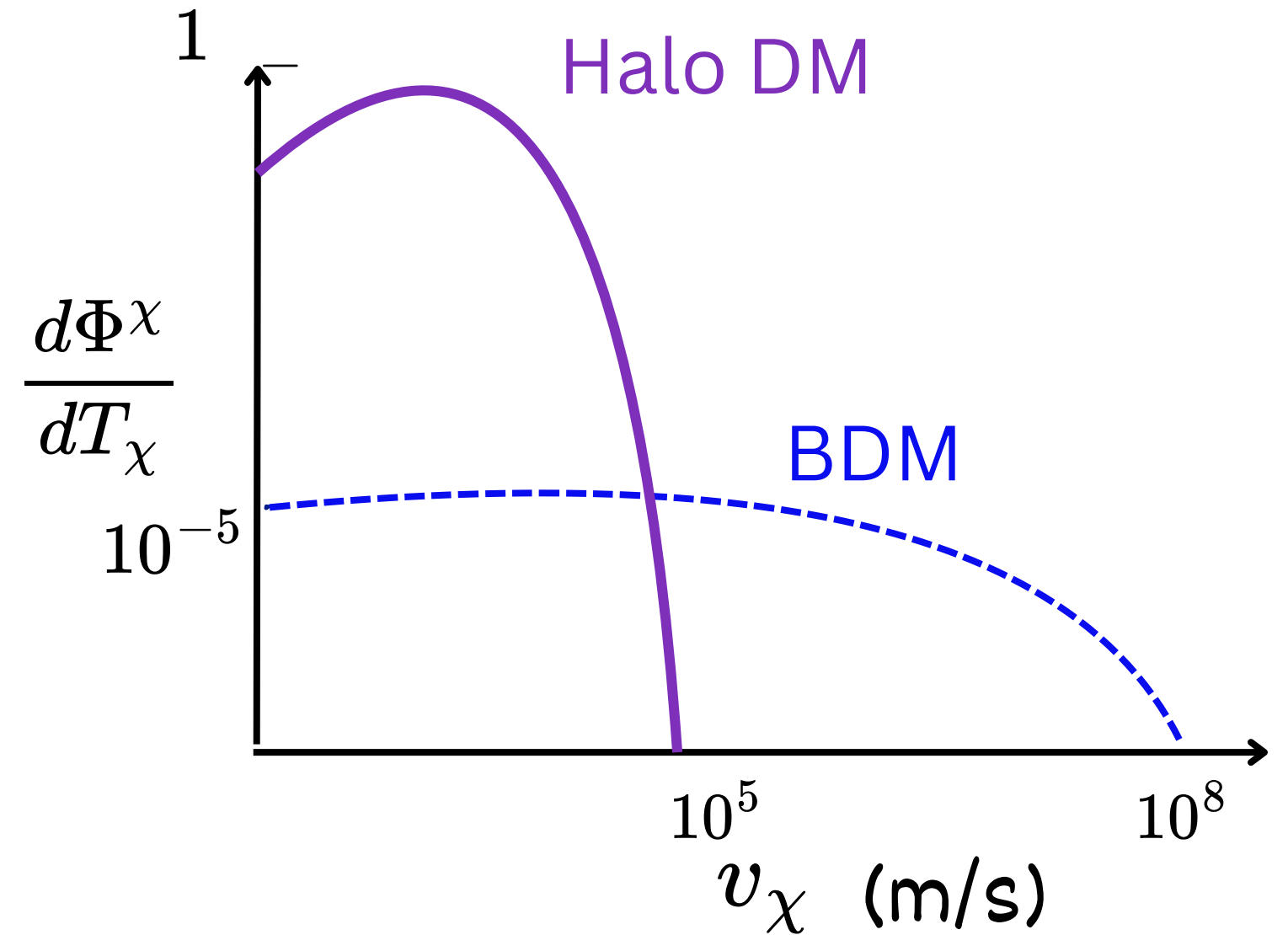


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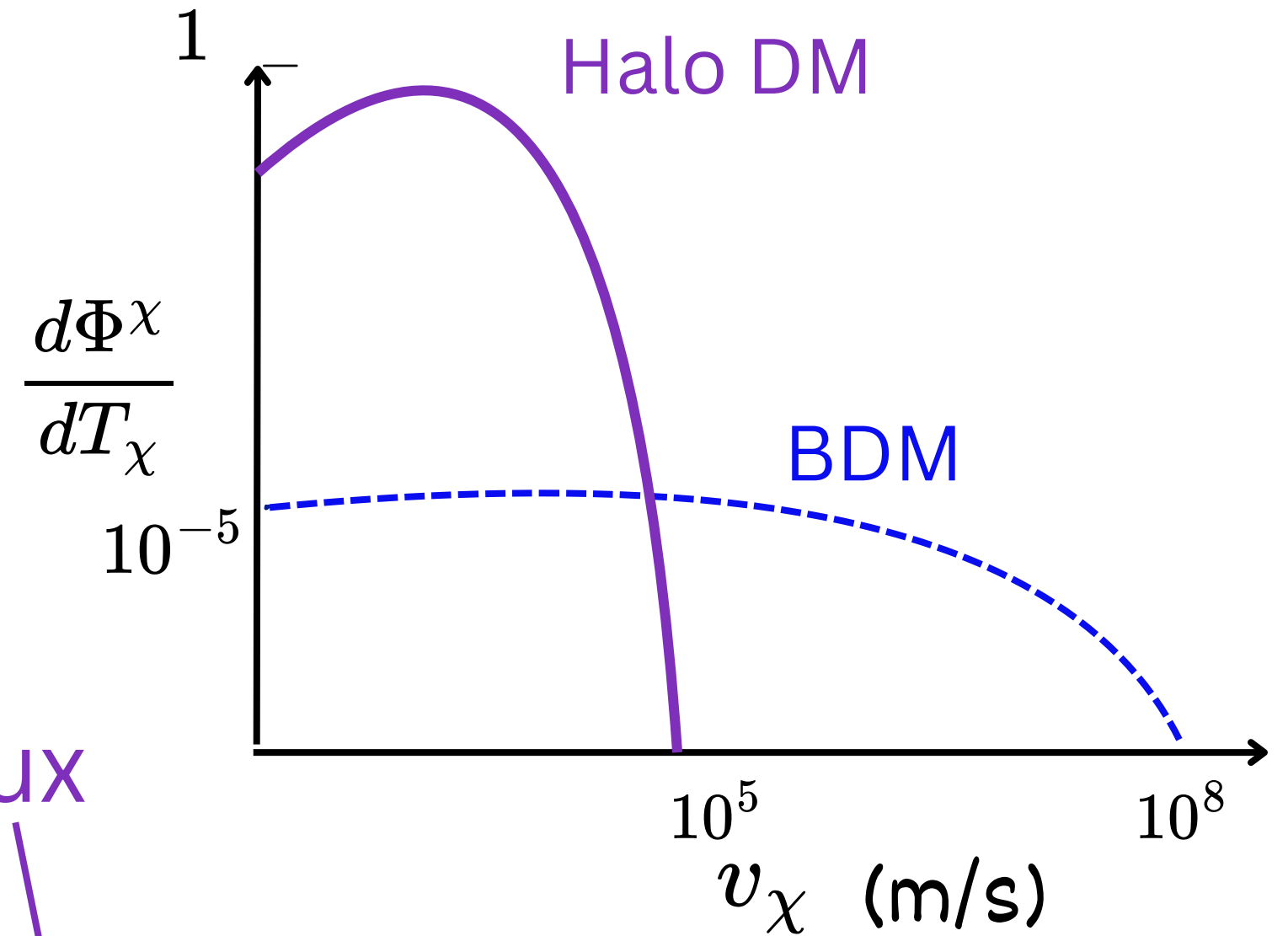
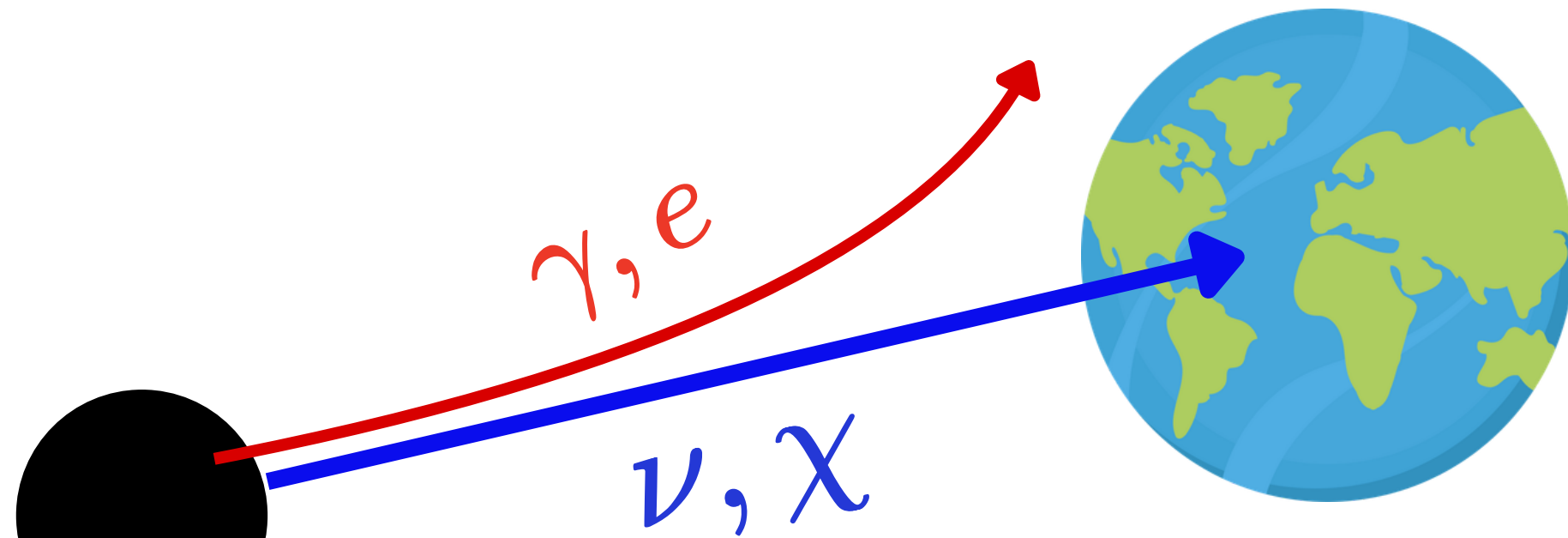
Electrophilic DM



Event rate:

$$\frac{dR}{dE_R} = t_{\text{exp}} N_T Z_{\text{eff}}(E_R) \int d\Omega \int_{T_\chi^{\min}(E_R)}^{T_\chi^{\max}} dT_\chi \frac{d^2\Phi_\chi}{dT_\chi d\Omega} \frac{d\sigma_{\chi e}}{dE_R}$$

Dark particle from PBH



Detector details

BDM flux

Event rate:

$$\frac{dR}{dE_R} = t_{\text{exp}} \boxed{N_T Z_{\text{eff}}(E_R)} \int d\Omega \int_{\boxed{T_\chi^{\min}(E_R)}}^{T_\chi^{\max}} dT_\chi \overbrace{\frac{d^2\Phi_\chi}{dT_\chi d\Omega}}^{\text{BDM flux}} \frac{d\sigma_{\chi e}}{dE_R}$$

DM Interaction

Recoil signature

- BDM flux depends on the type of interaction

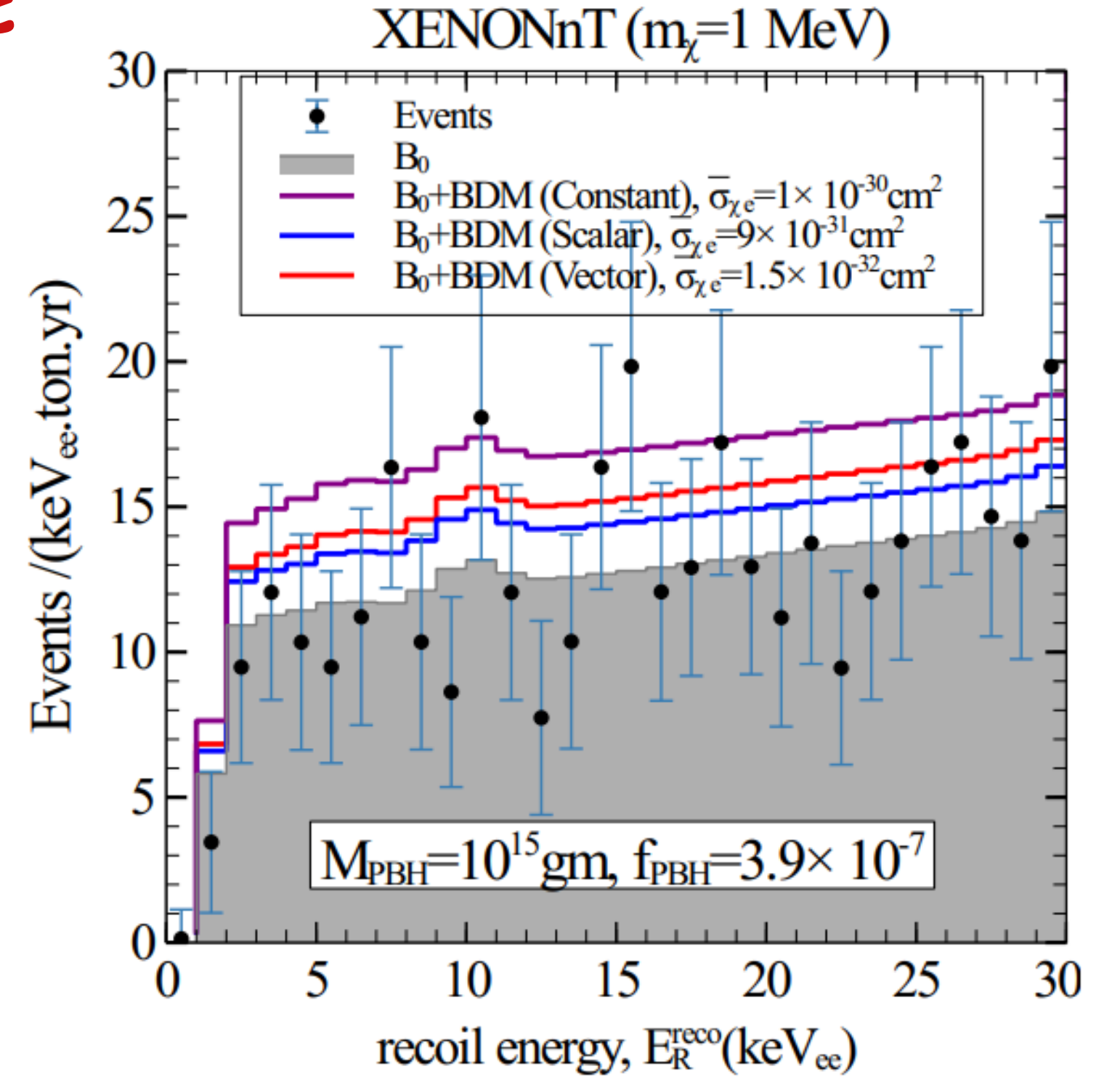
Constant : $\left(\frac{d\sigma_{\chi e}}{dE_R} \right)_c = \frac{\bar{\sigma}_{\chi e}}{E_R^{\max}(T_\chi)}$

Energy dependent:

$$\left(\frac{d\sigma_{\chi e}}{dE_R} \right)_s = \bar{\sigma}_{\chi e} \left(\frac{m_e}{4\mu_{e\chi}^2} \right) \frac{(2m_e + E_R)(2m_\chi^2 + m_e E_R)}{s_\chi E_R^{\max}}$$

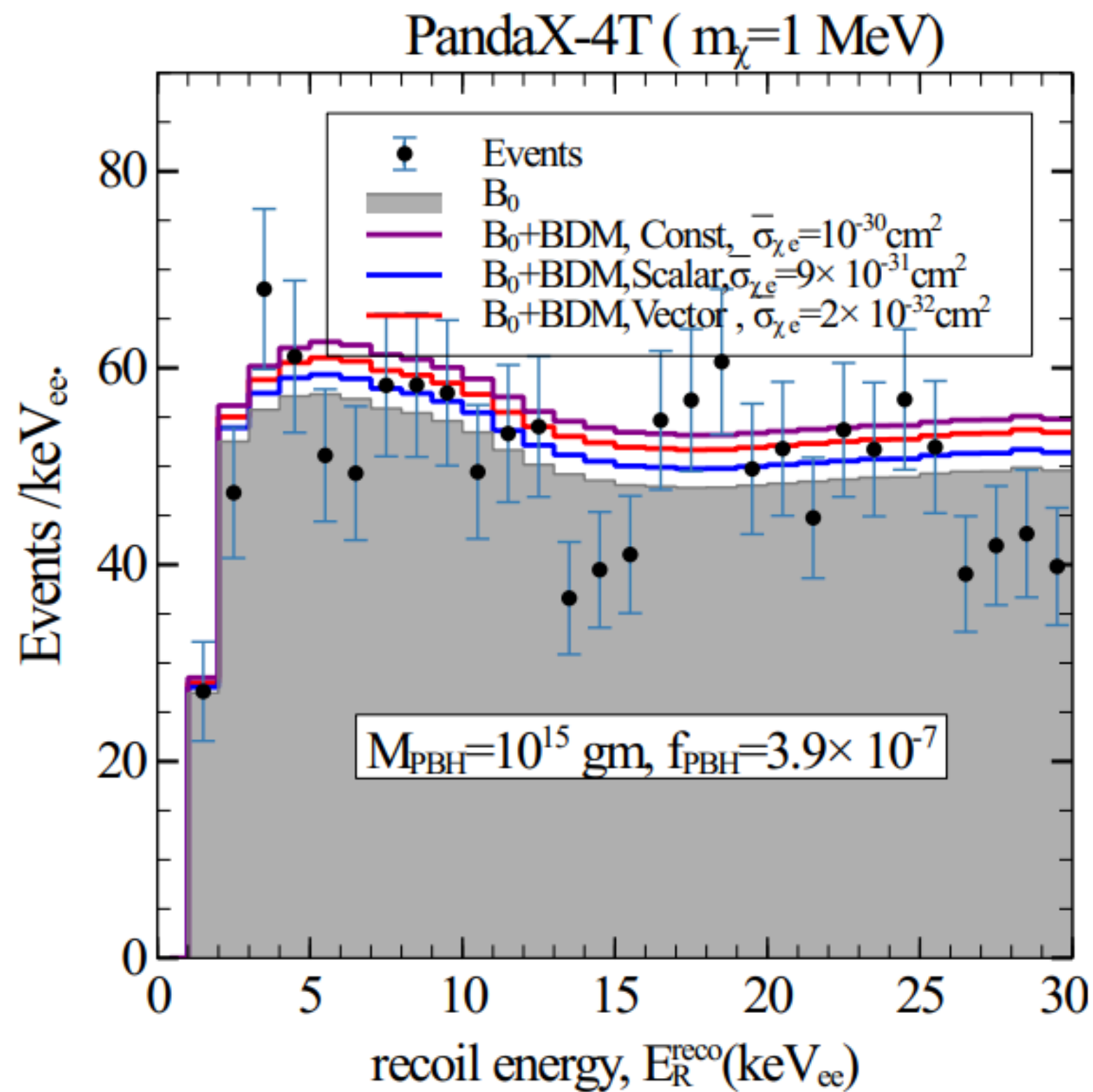
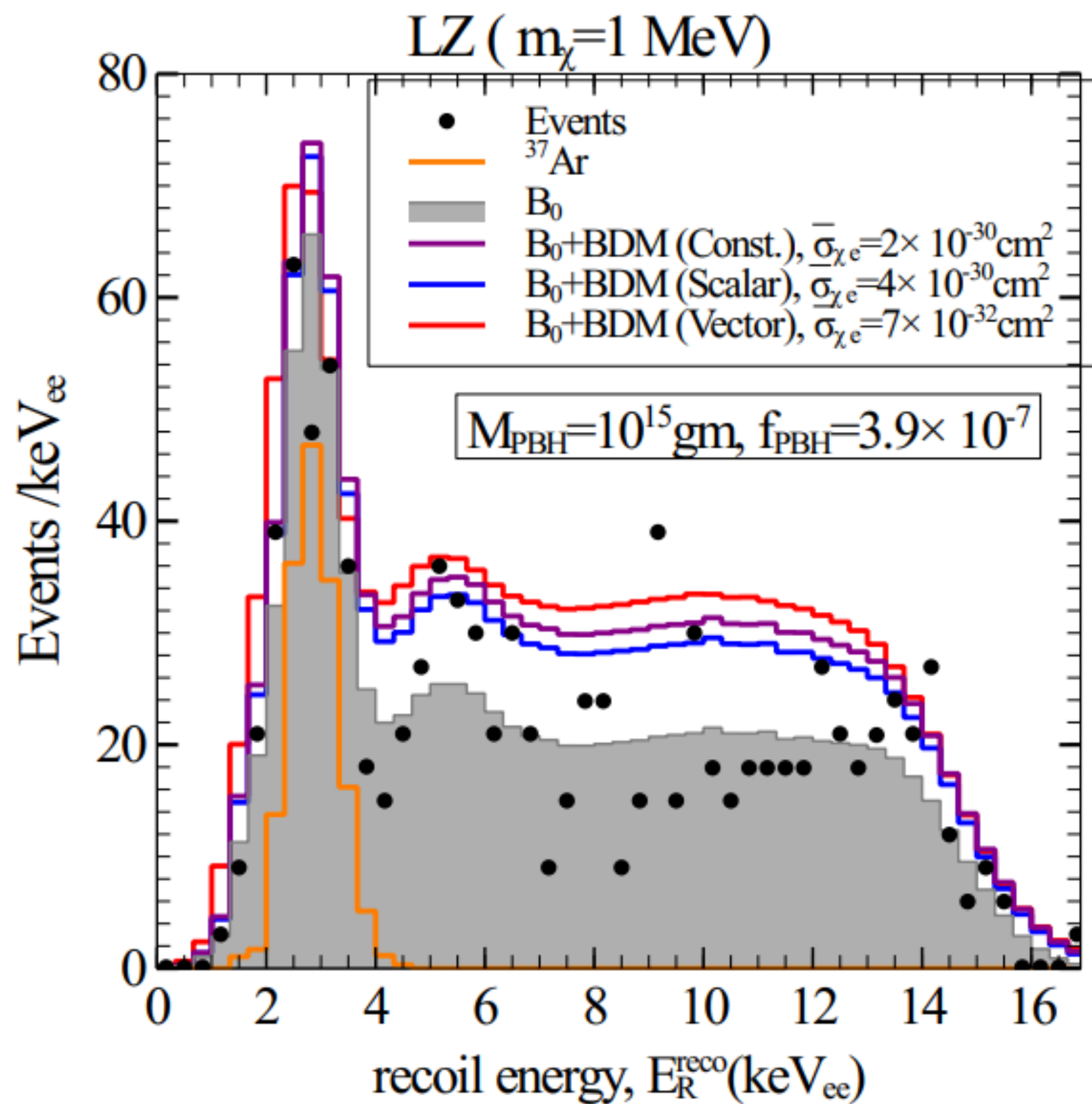
$$\left(\frac{d\sigma_{\chi e}}{dE_R} \right)_v = \bar{\sigma}_{\chi e} \left(\frac{m_e}{2\mu_{e\chi}^2} \right) \left(2m_e(m_\chi + T_\chi)^2 - E_R((m_e + m_\chi)^2 + 2m_e T_\chi) + m_e E_R^2 \right) / (s_\chi E_R^{\max})$$

$$s_\chi = (m_\chi + m_e)^2 + 2m_e T_\chi$$

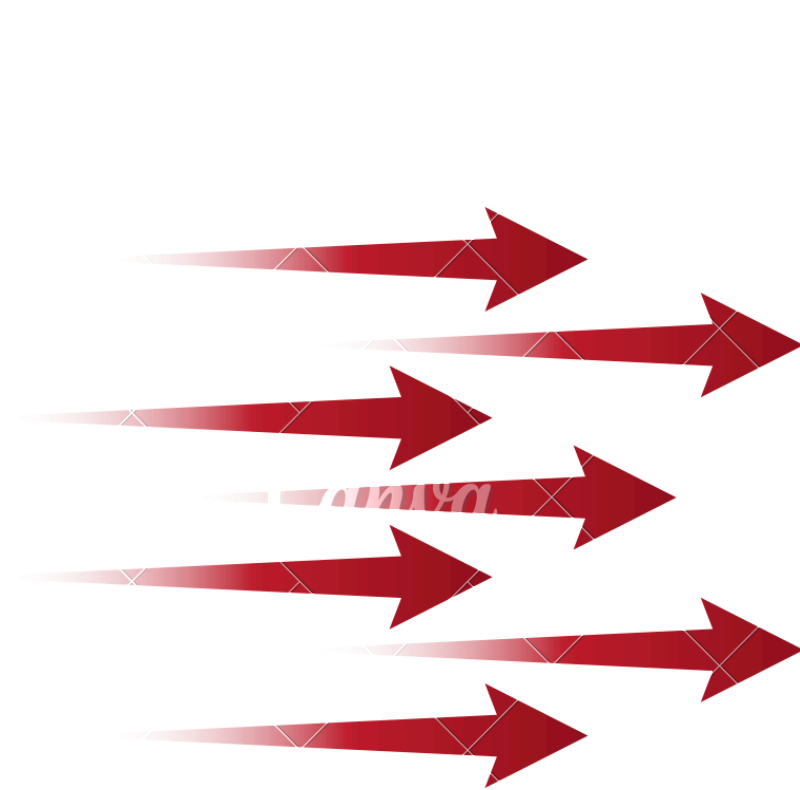


$$E_R^{\max} = \frac{T_\chi^2 + 2m_\chi T_\chi}{T_\chi + (m_\chi + m_e)^2 / (2m_e)}$$

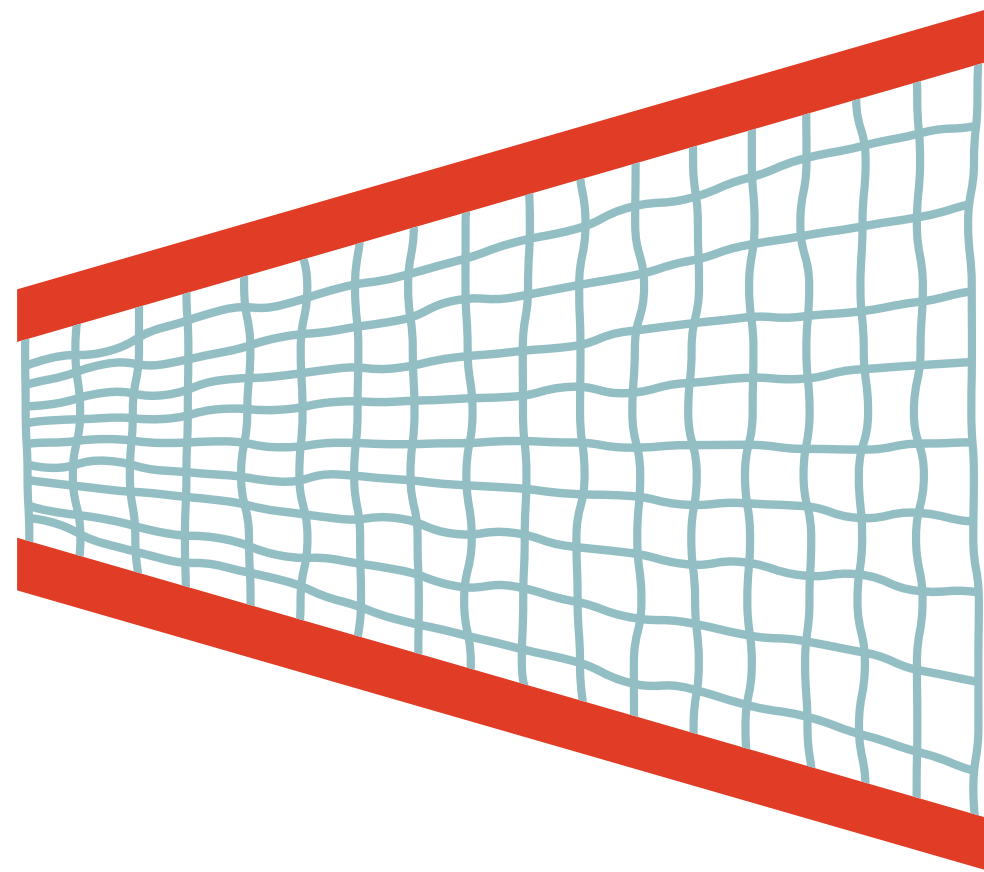
Recoil signature



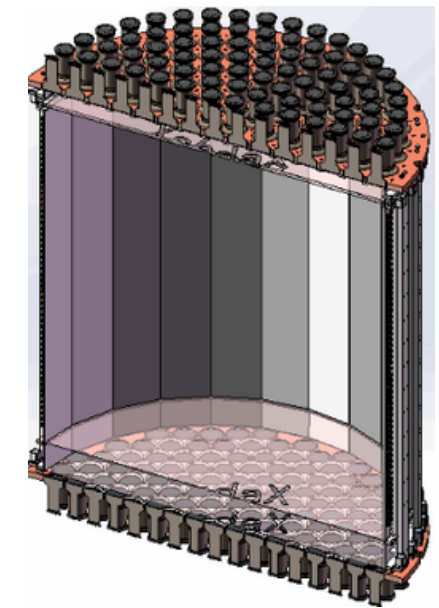
Attenuation effect



High velocity DM



Collision with earth's
electrons before
reaching detector



Detector

Attenuation effect

KE at depth z

$$\frac{dT_{\chi}^z}{dz} = -n_e \int_0^{T_{er}^{\max}(T_{\chi}^z)} \frac{d\sigma_{\chi e}}{dT_{er}} T_{er} dT_{er},$$

$$z = -(R_{\oplus} - h_d) \cos \theta_z + \sqrt{R_{\oplus}^2 - (R_{\oplus} - h_d)^2 \sin^2 \theta_z}.$$

BDM flux at depth z

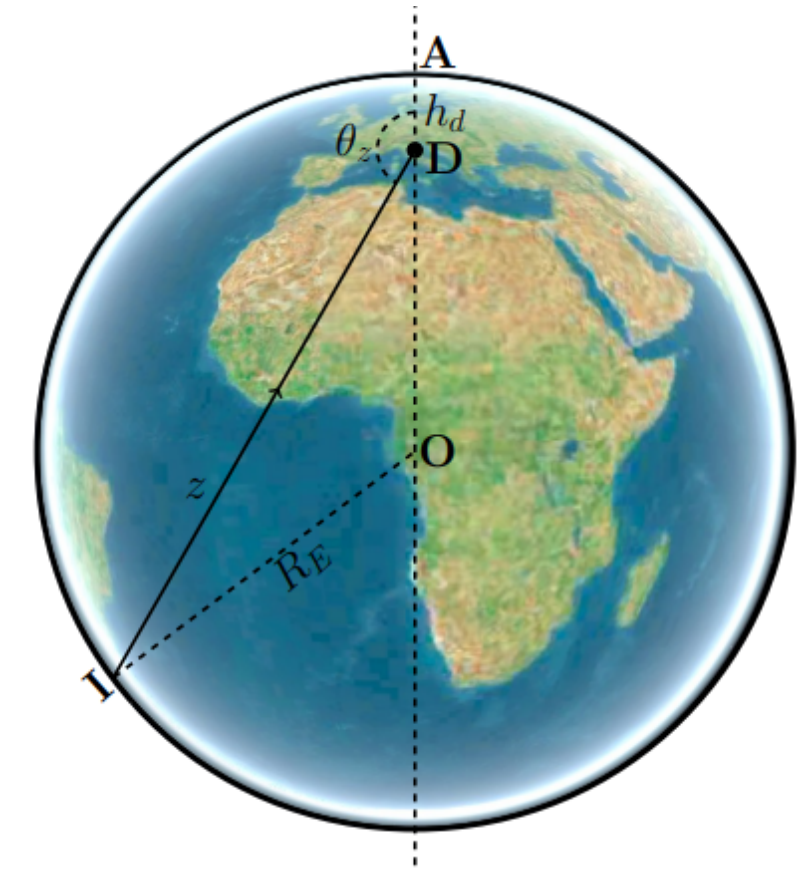
$$\frac{d\Phi_{\chi}}{dT_{\chi}^z} = \int d\Omega \left. \frac{d^2\Phi_{\chi}}{dT_{\chi} d\Omega} \right|_{T_{\chi}^0} \frac{dT_{\chi}^0}{dT_{\chi}^z}.$$

Analytical solution:

$$T_{\chi}^z \approx \frac{T_{\chi}^0 e^{-z/l_E}}{1 + \frac{T_{\chi}^0}{2m_{\chi}} (1 - e^{-z/l_E})}$$

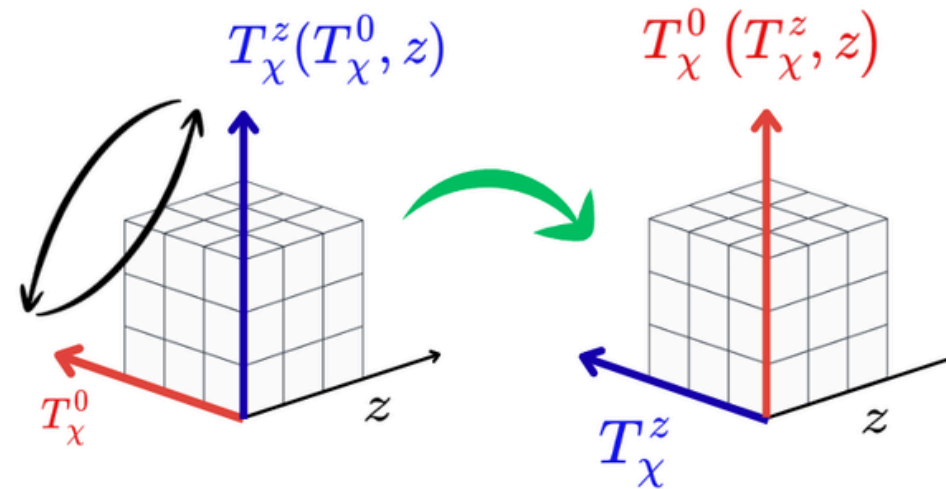
$$l_E^{-1} = n_e \bar{\sigma}_{\chi e} \frac{2m_e m_{\chi}}{(m_e + m_{\chi})^2}.$$

- Valid only when, $(m_{\chi} + m_e)^2 \ll 2m_e T_{\chi}^z$ and, **energy-indep.** x-section

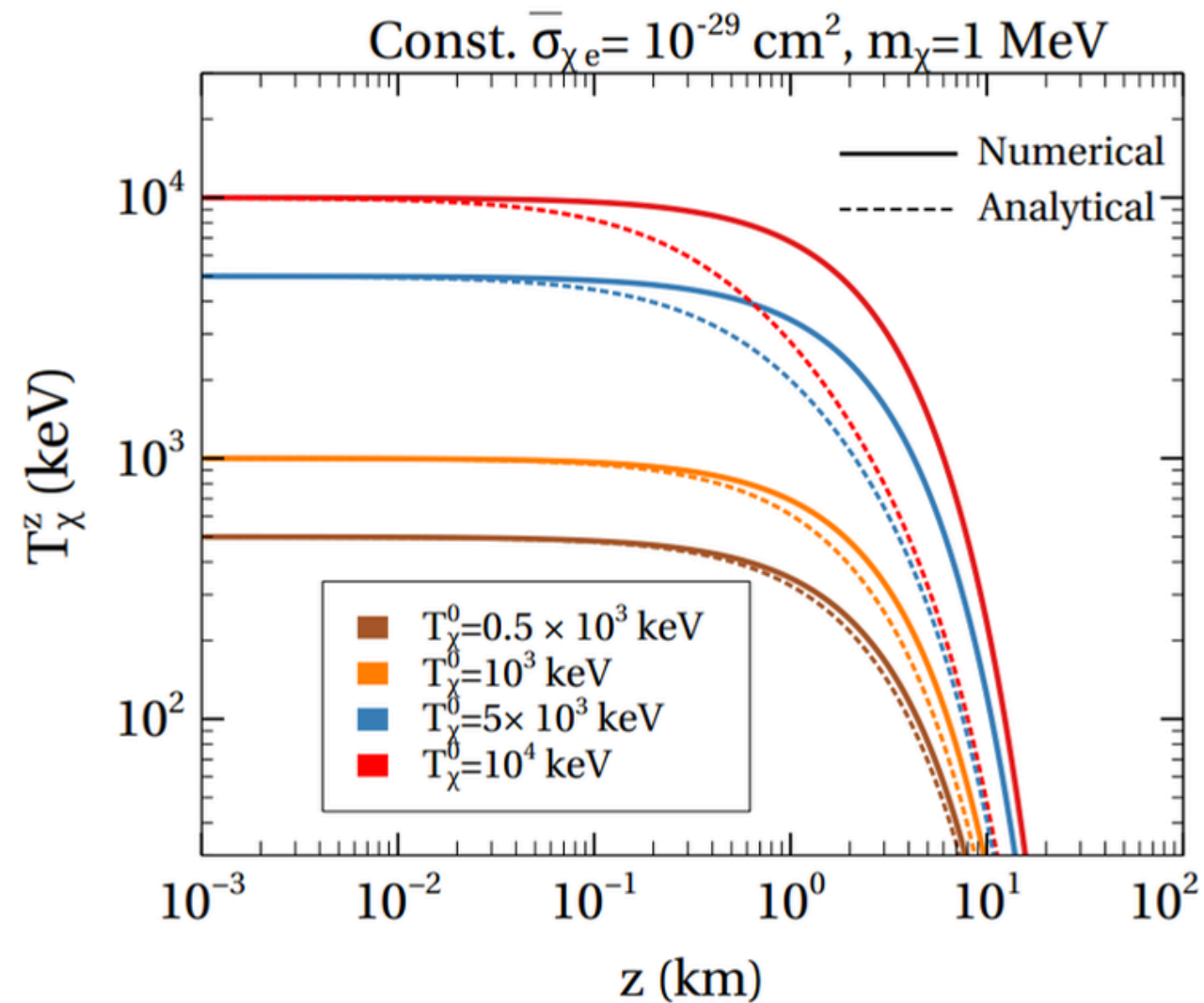


Attenuation effect: Numerical treatment

for fixed $\sigma_{\chi e}$ and m_χ

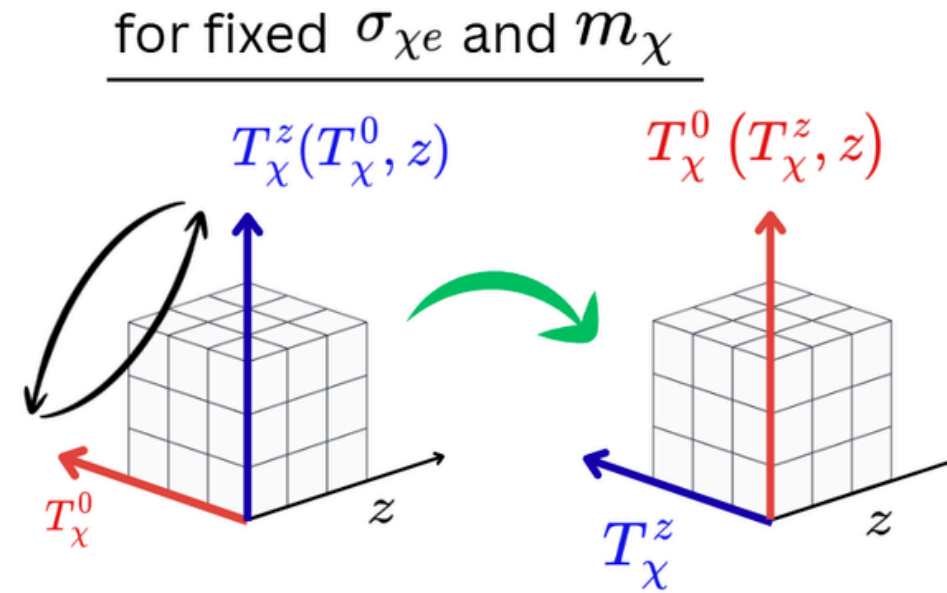
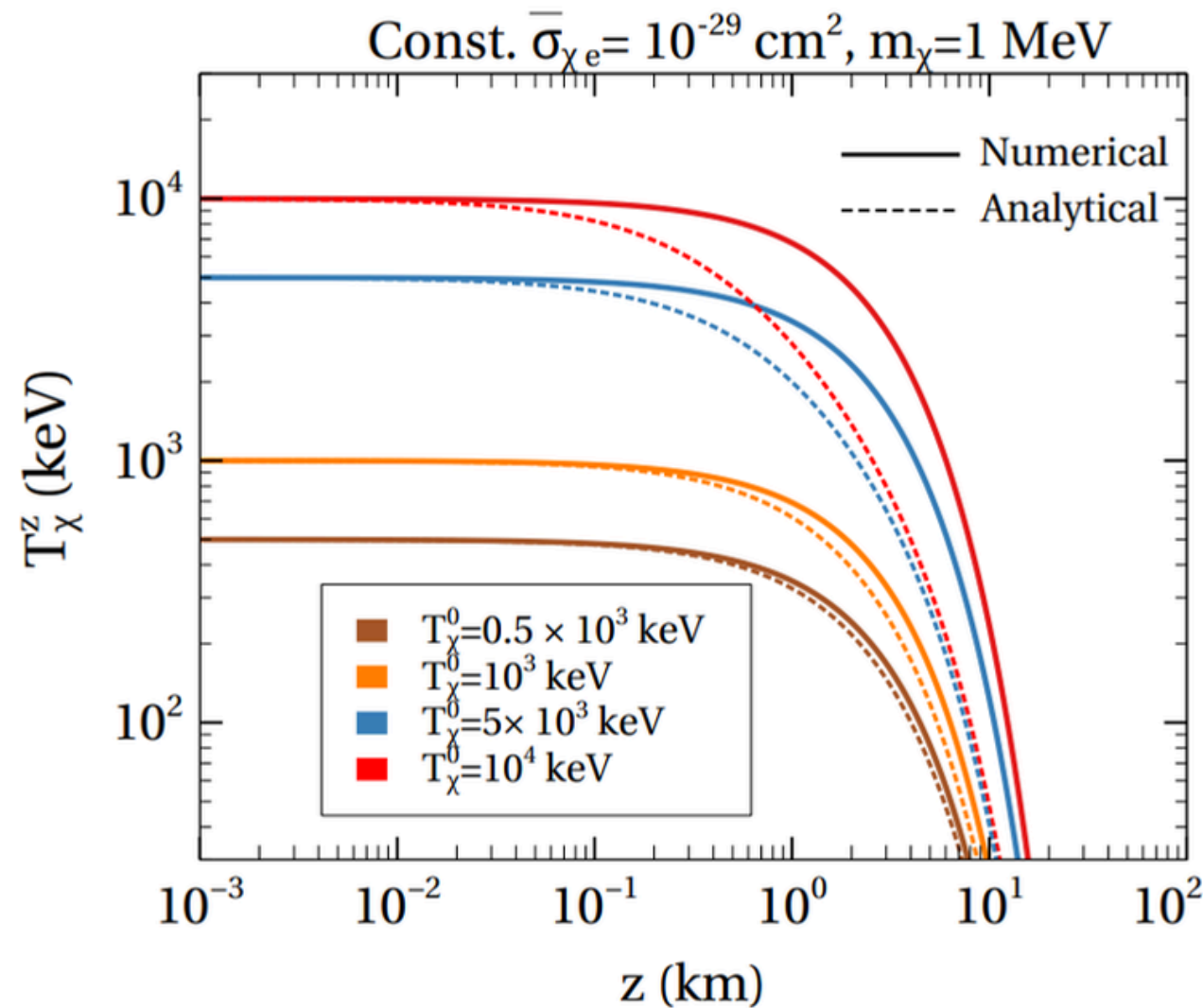


Step I.



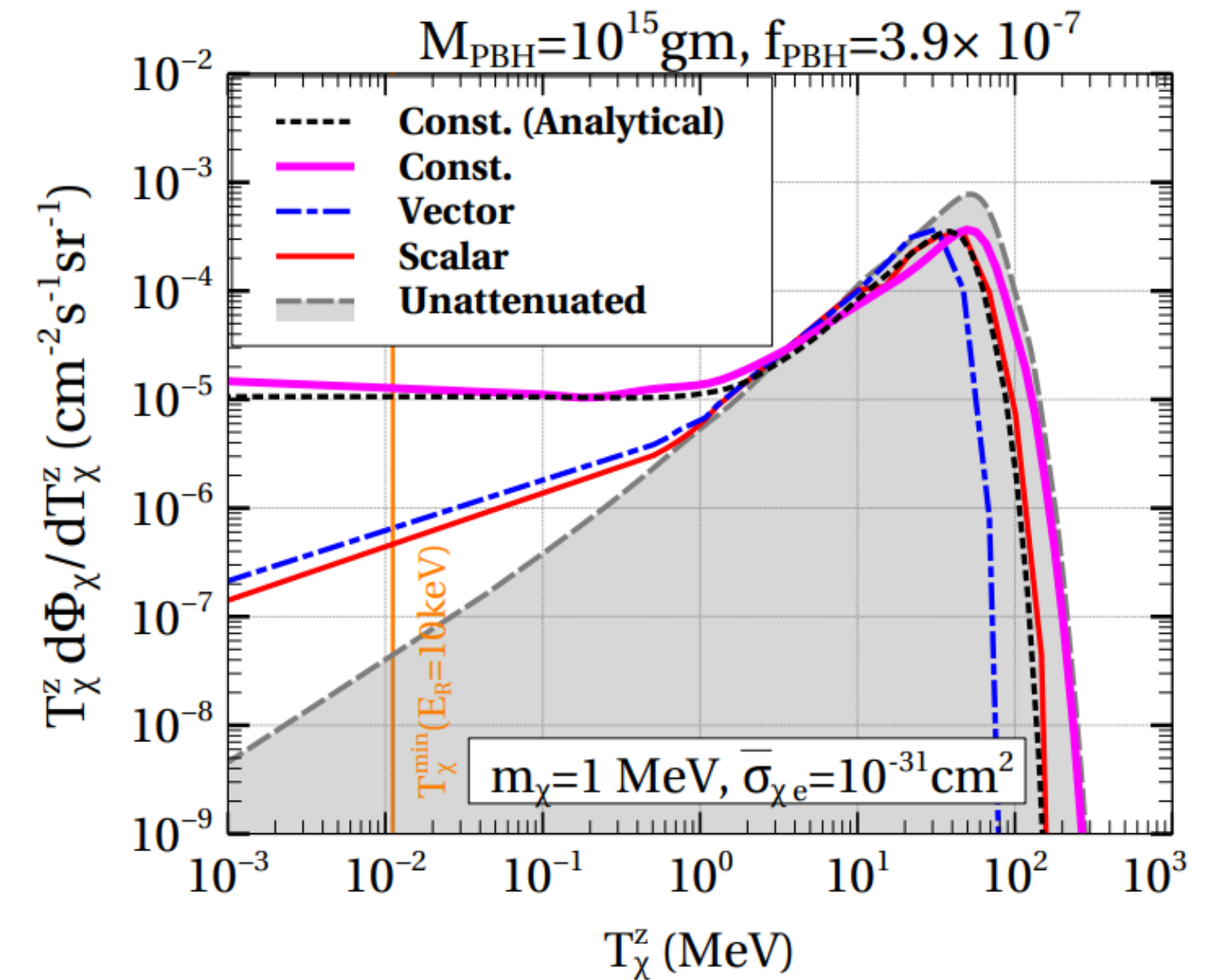
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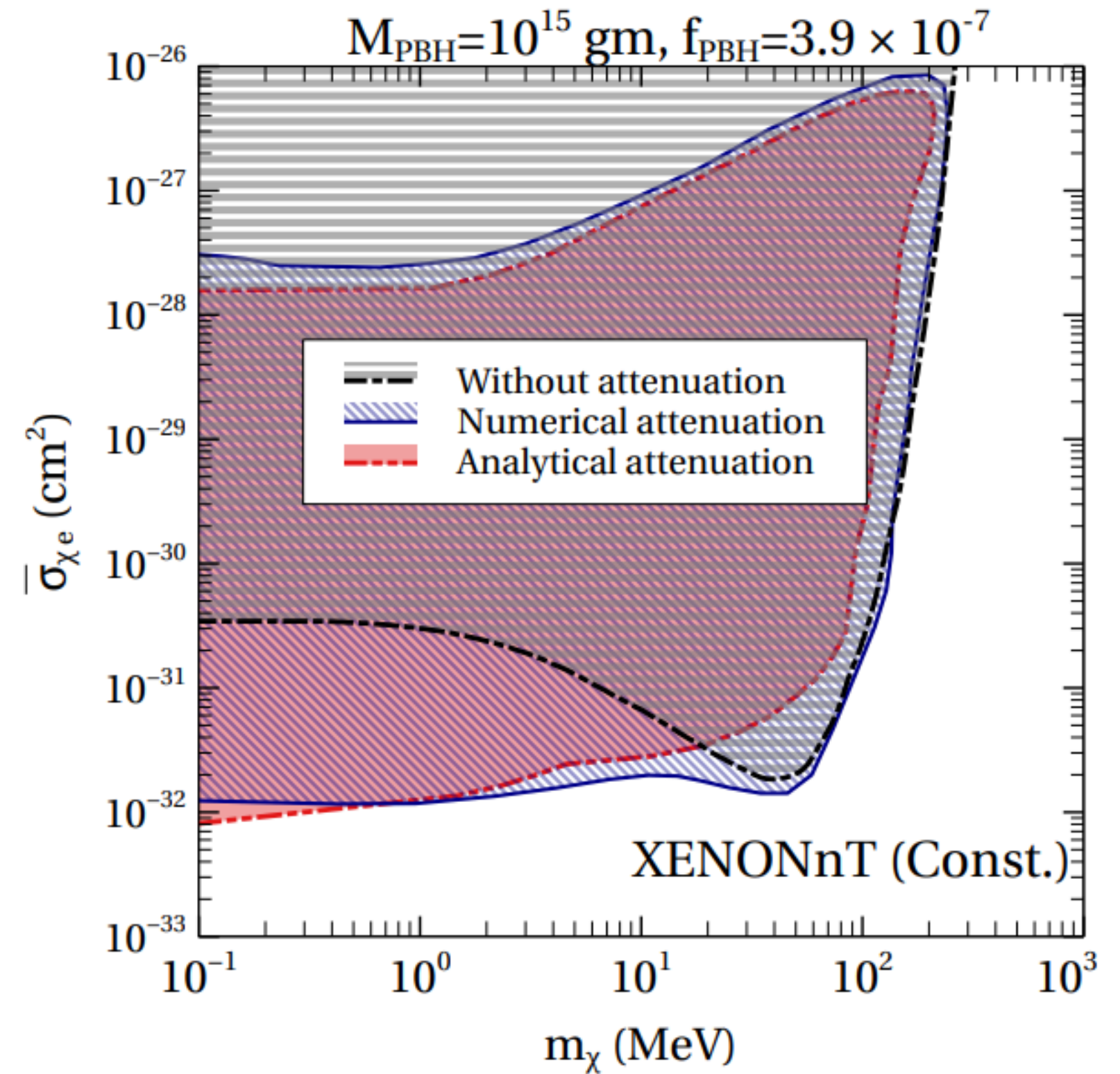
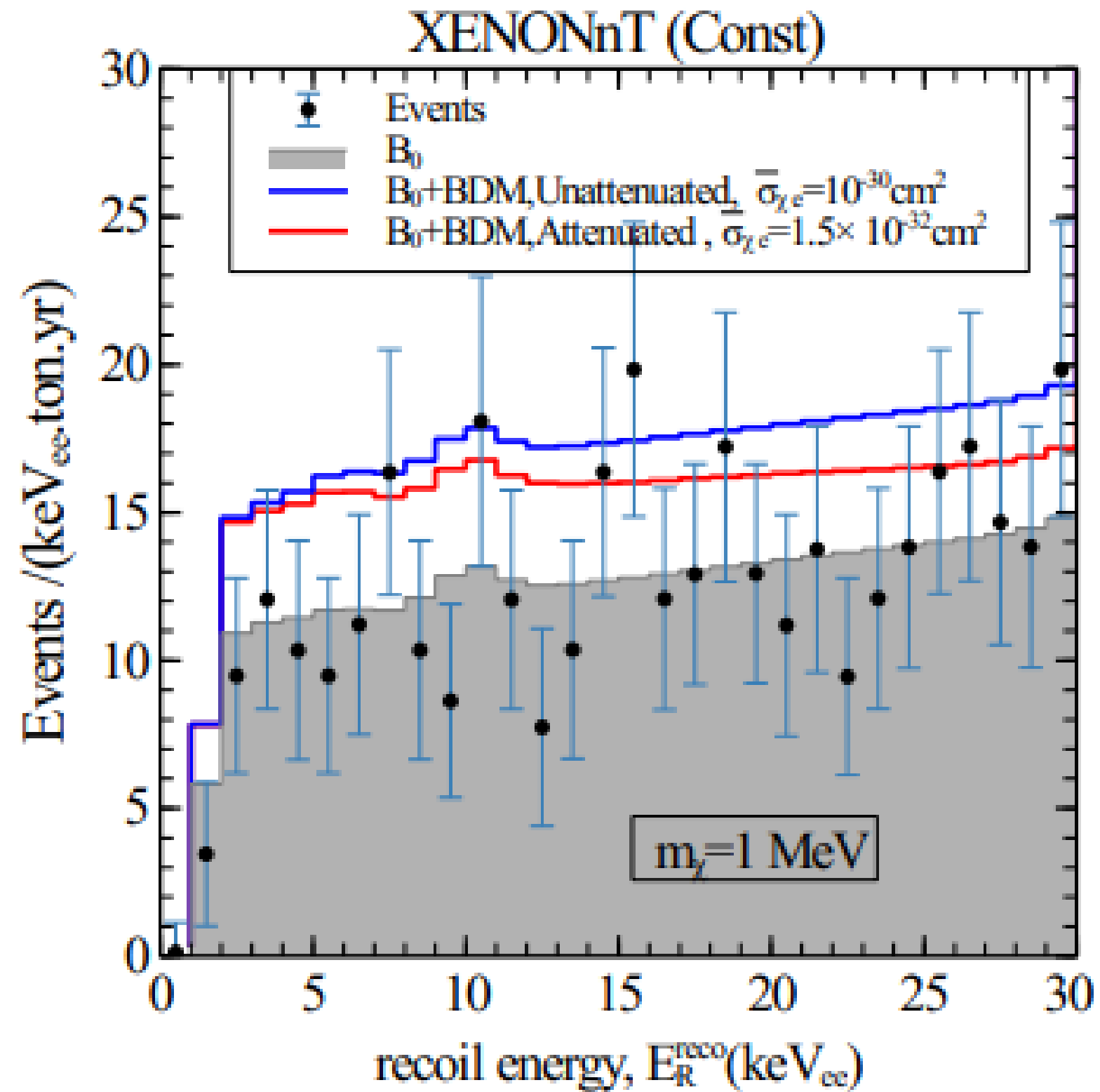


$$\frac{d\Phi_\chi}{dT_\chi^z} = \int d\Omega \left. \frac{d^2\Phi_\chi}{dT_\chi d\Omega} \right|_{T_\chi^0} \frac{dT_\chi^0}{dT_\chi^z}.$$

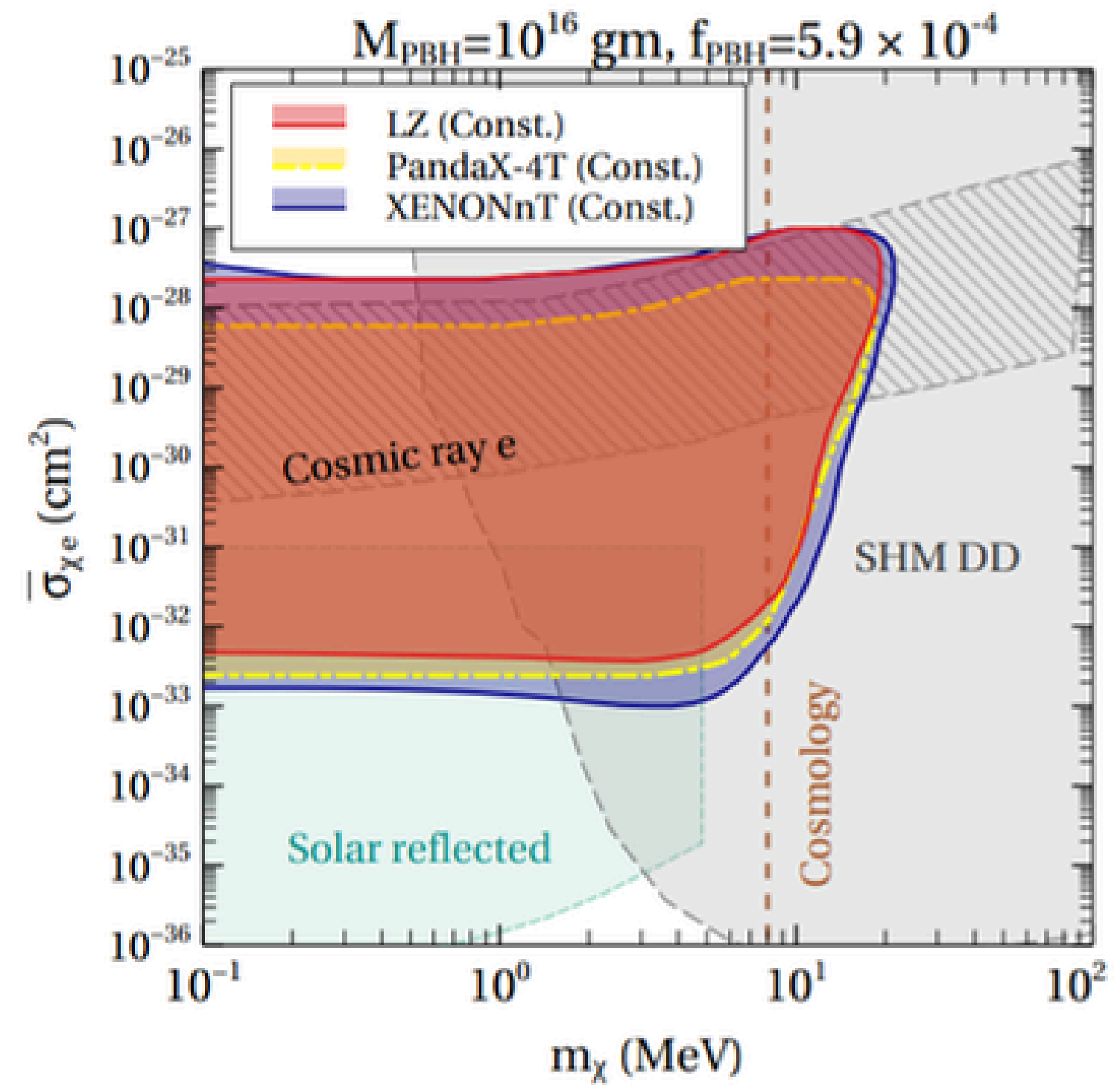
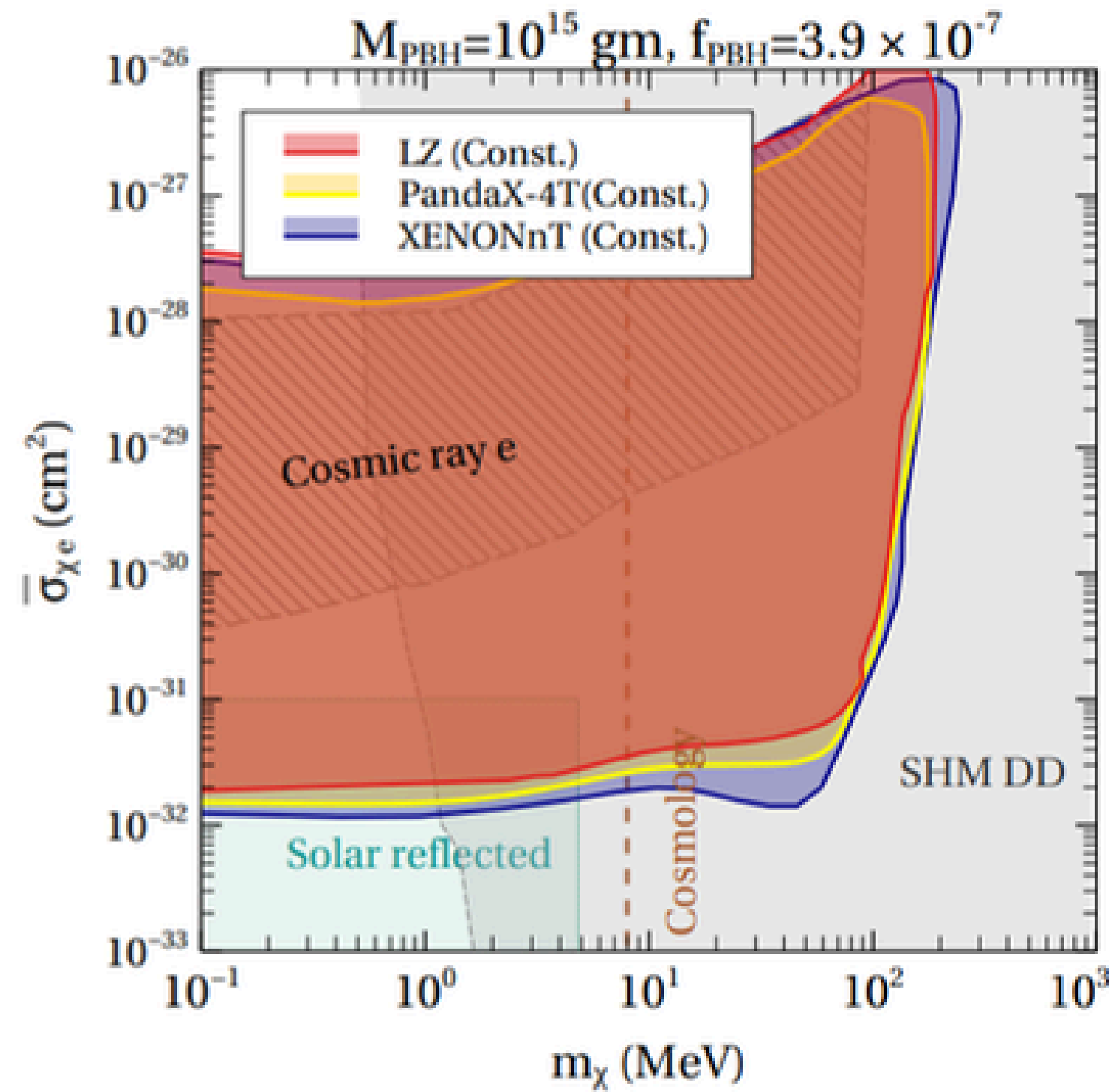
Step II.



Constraints on PBH evaporated DM

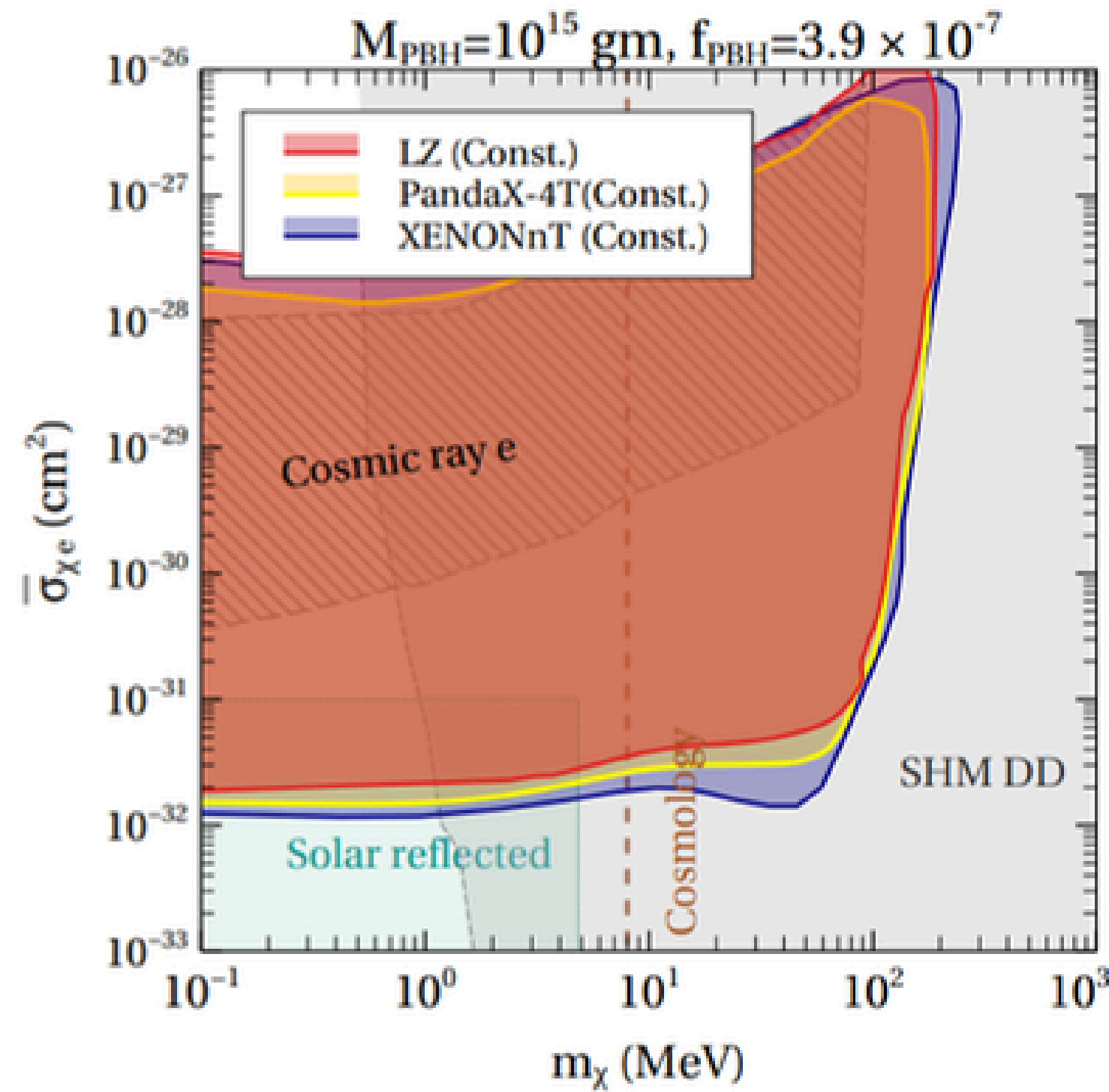


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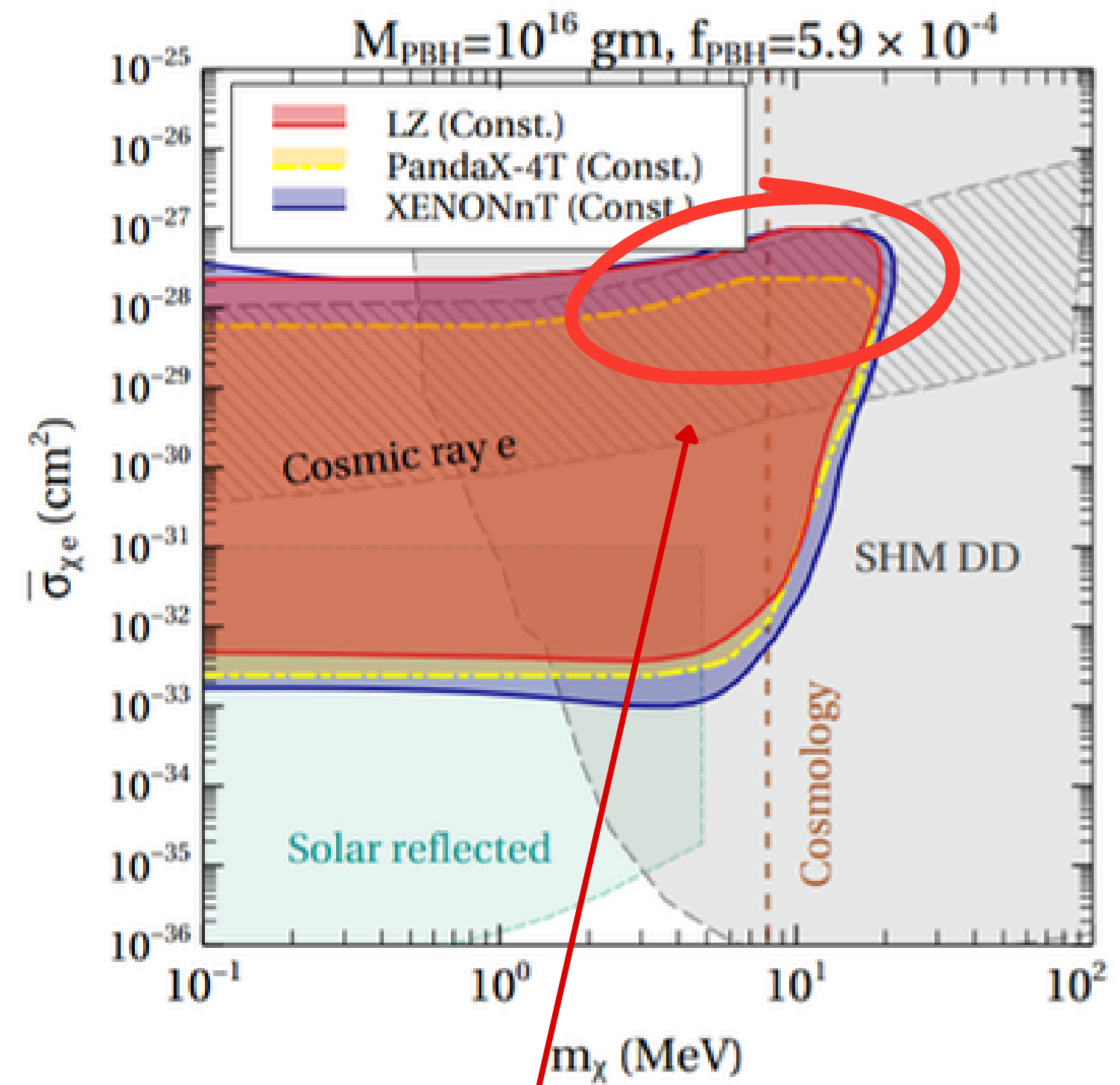


Energy independent interaction

Constraints on PBH evaporated DM

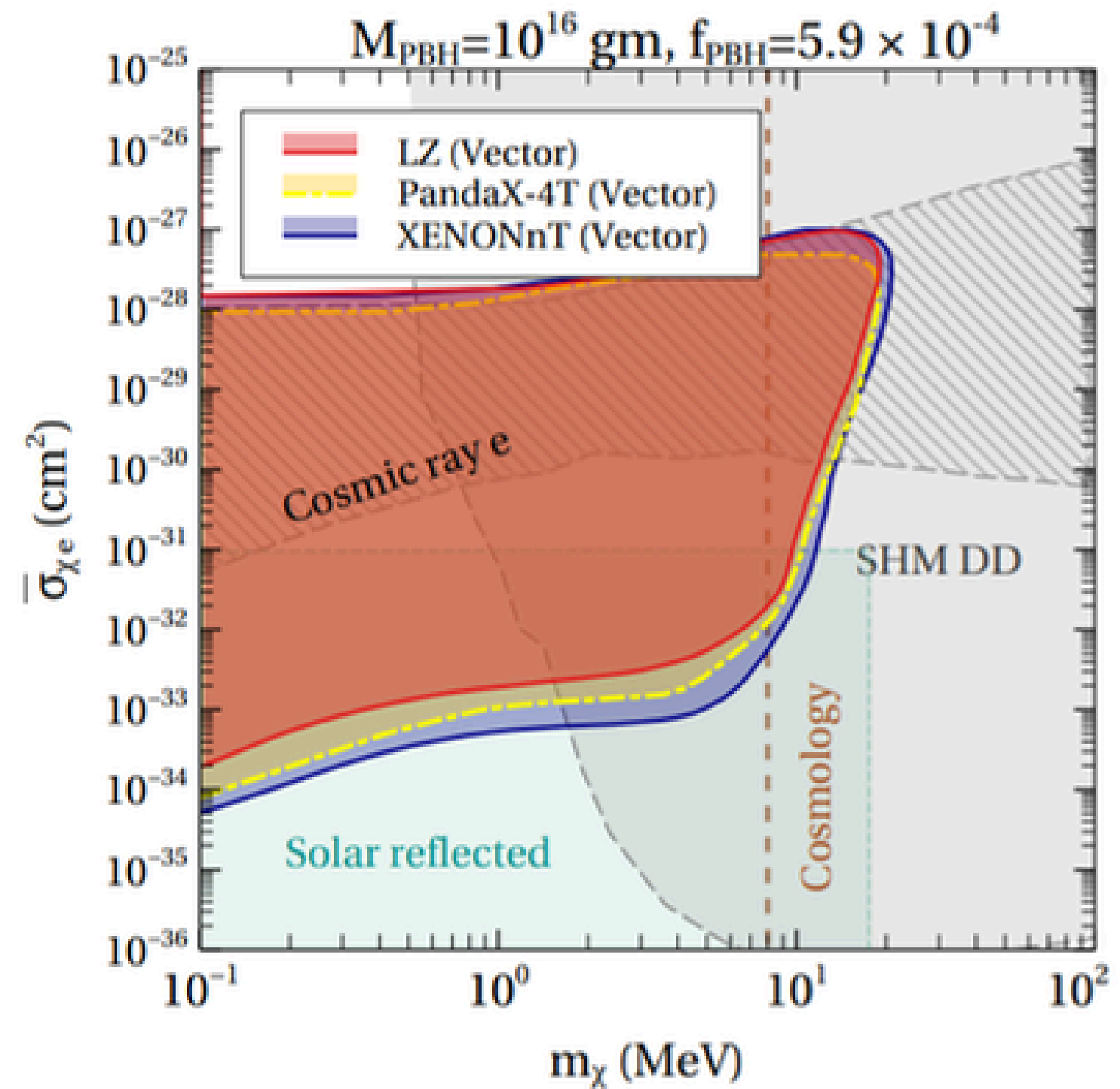
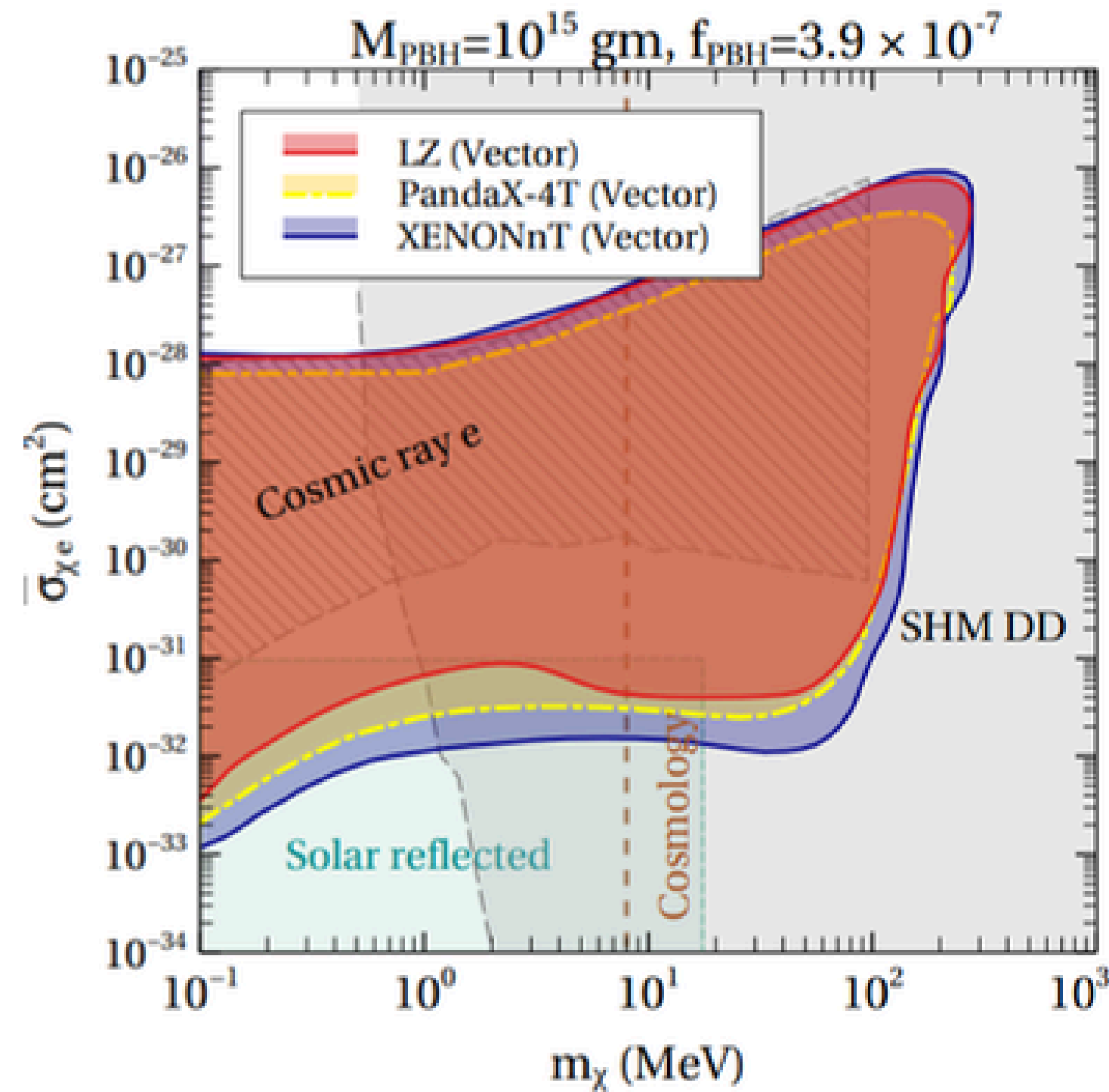


Energy independent interaction



depth @ PandaX-4T > XENONnT, LZ

Constraints on PBH evaporated DM



Energy dependent interaction: Vector mediated

Summary

- Since we have reached the neutrino fog for EW scale DM, it is now time to search light DM
- PBH evaporated DM can offer new parameter reaches
- For BDM, event-rate/ exclusion limits depend strongly on interaction type and mediator mass, $\rightarrow$ holistic analysis is required
- Attenuation strongly affects DM limit $\rightarrow$ numerical treatment required for energy dependent interactions.

Thank you