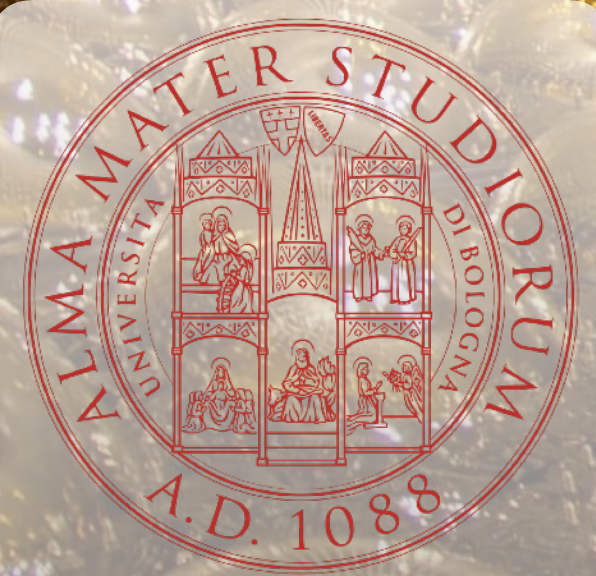


Sub-GeV Dark Matter at Large Neutrino Detectors

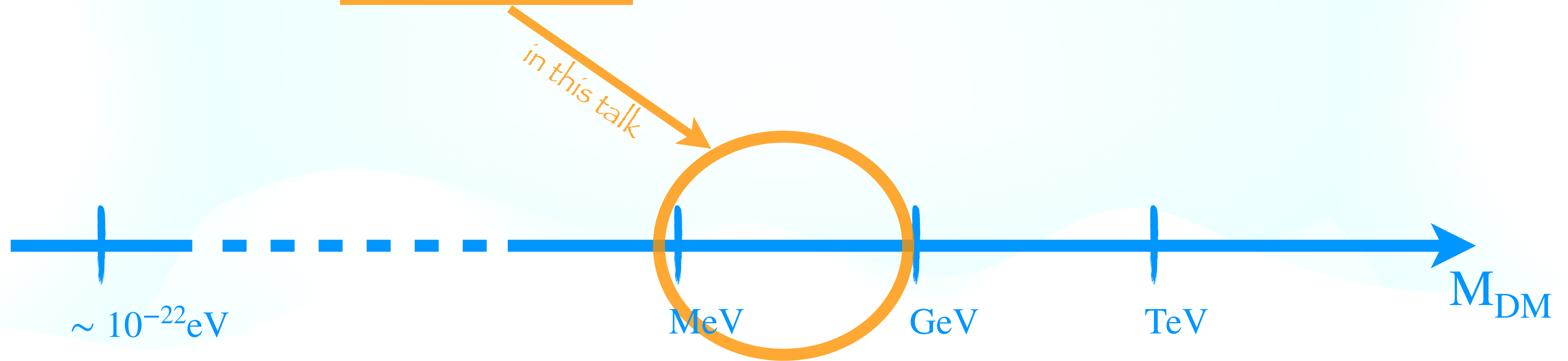
Filippo Sala
U. Bologna

Light Dark World, Karlsruhe

20 Sep 2023



Sub-GeV Dark Matter



Why?

Cosmo histories motivate it/exist

We can look for it “easily”

Direct Detection of Sub-GeV Dark Matter ?

For **Indirect Detection**
listen to **Jordan Koechler**

Direct Detection of Sub-GeV Dark Matter ?

Challenge

$$E_{\text{NR}} = \frac{q^2}{2m_N} \leq \frac{2\mu_{\chi N}^2 v_\chi^2}{m_N} \lesssim \boxed{190 \text{ eV}} \times \left(\frac{m_\chi}{500 \text{ MeV}} \right)^2 \left(\frac{16 \text{ GeV}}{m_N} \right)$$

Solutions 1: lower m_N

Solutions 2: lower the thresholds

Direct Detection of Sub-GeV Dark Matter ?

Challenge

$$E_{\text{NR}} = \frac{q^2}{2m_N} \leq \frac{2\mu_{\chi N}^2 v_\chi^2}{m_N} \lesssim \boxed{190 \text{ eV}} \times \left(\frac{m_\chi}{500 \text{ MeV}} \right)^2 \left(\frac{16 \text{ GeV}}{m_N} \right)$$

Solutions 1: lower m_N

NEWS-G

e.g. [SciPost Phys. Proc. 12 \(2023\) 024](#)

...

Solutions 2: lower the thresholds

PHONON(S) & similar beasts

e.g. [Angelo Esposito @ this conf](#)

[Francesco Toschi @ this conf](#)

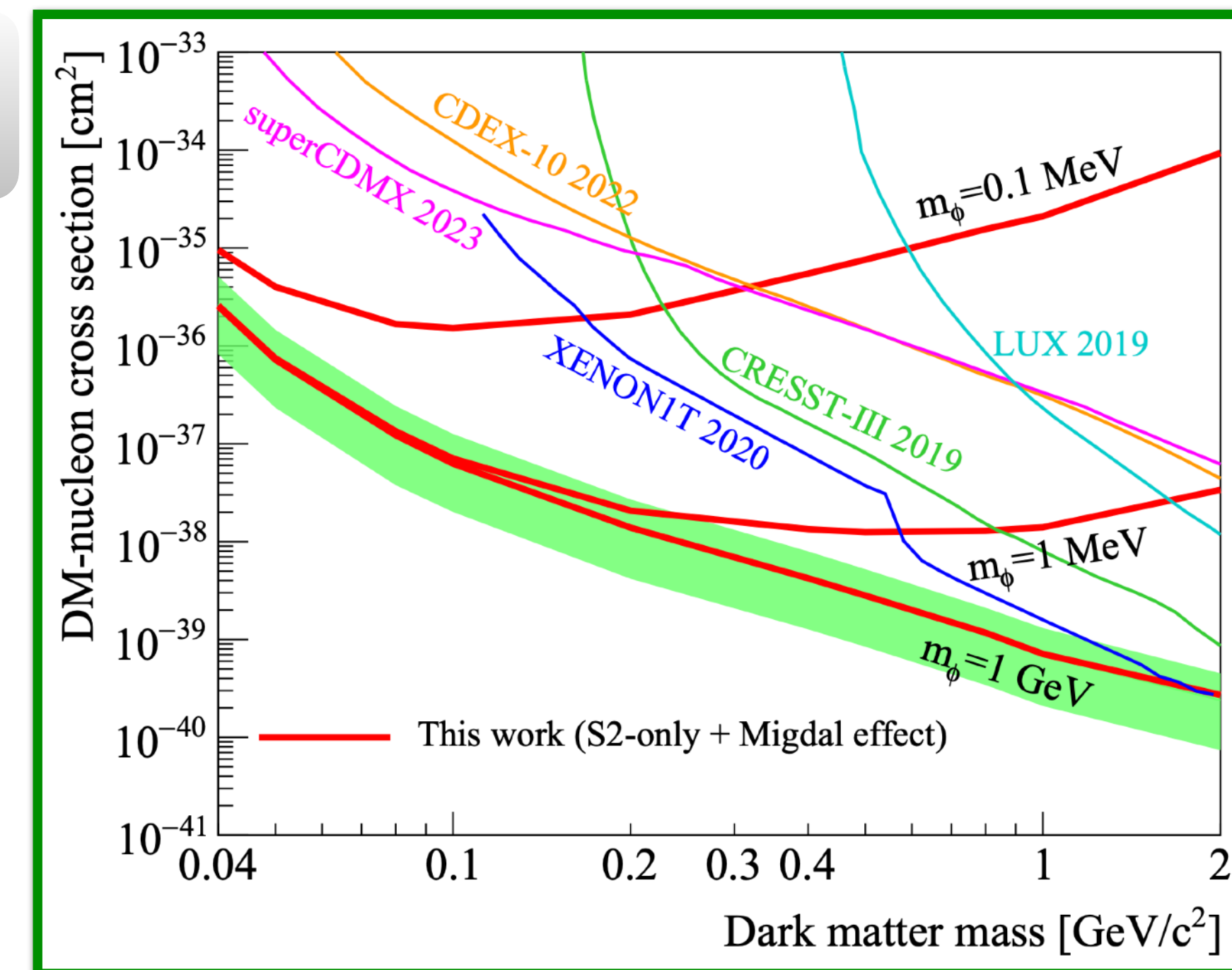
...

[Campbell-Deem+ 2205.02250](#) ...

MIGDAL e.g. [PANDA X 2308.01540](#)

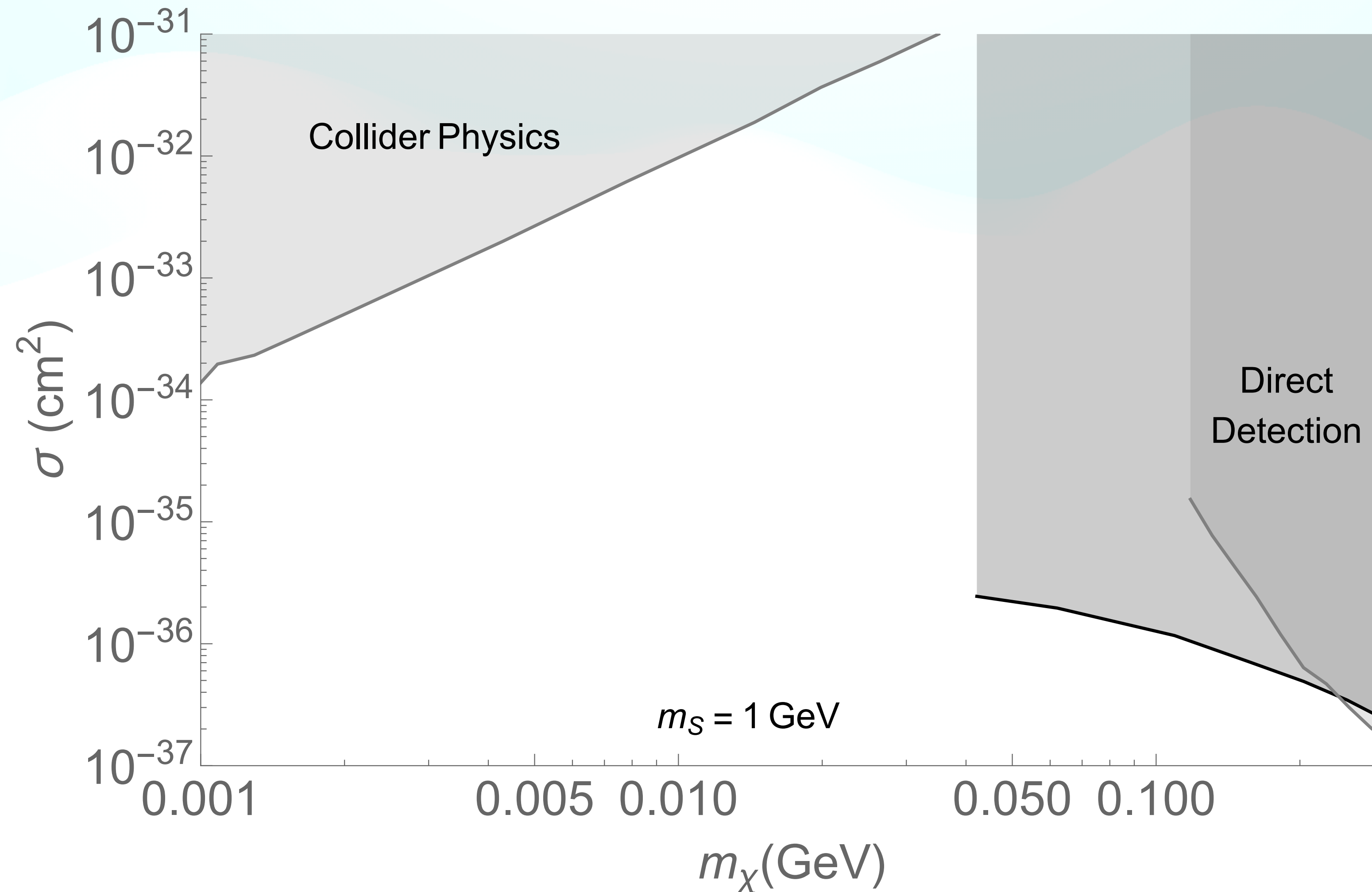
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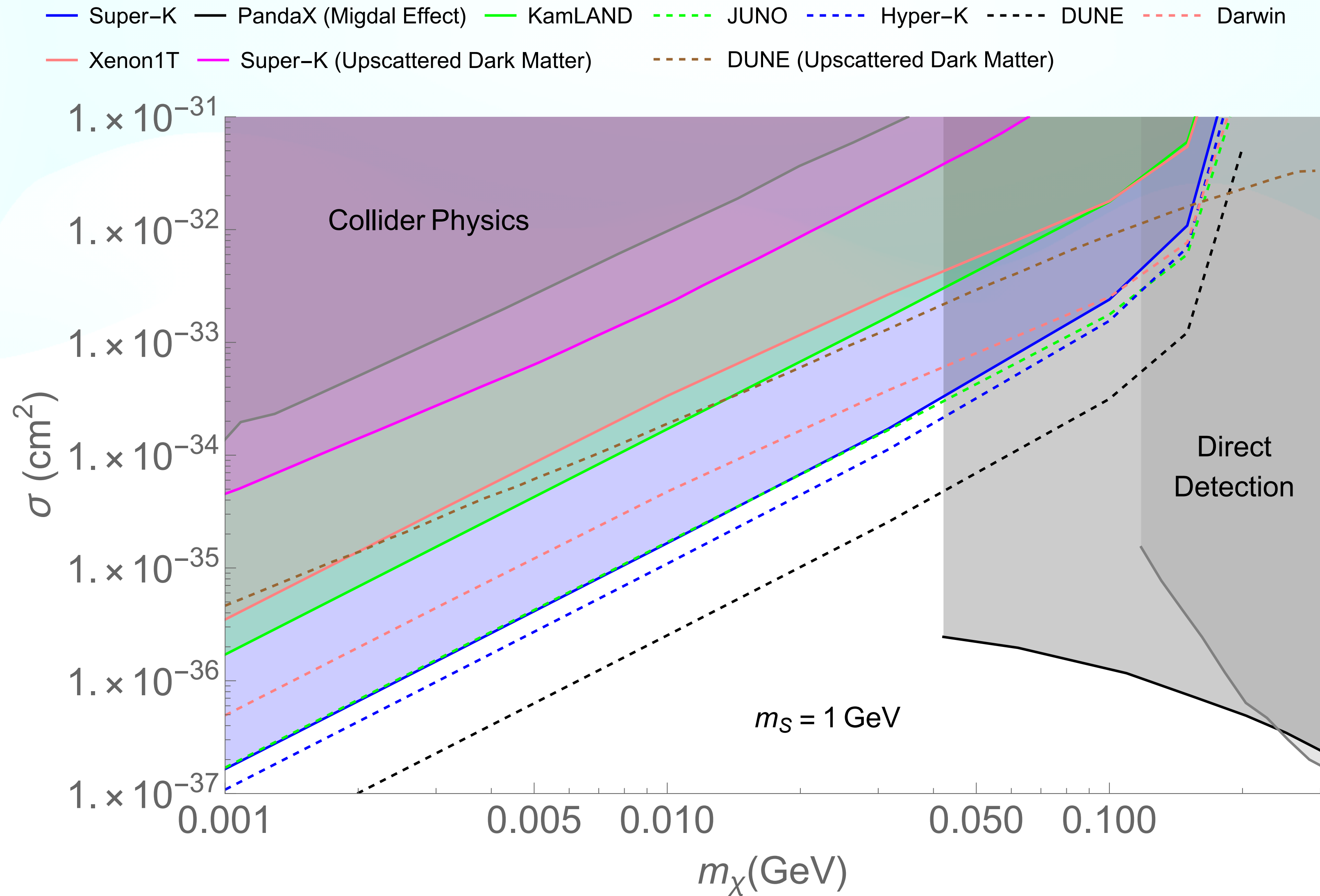


This Talk: from this ...

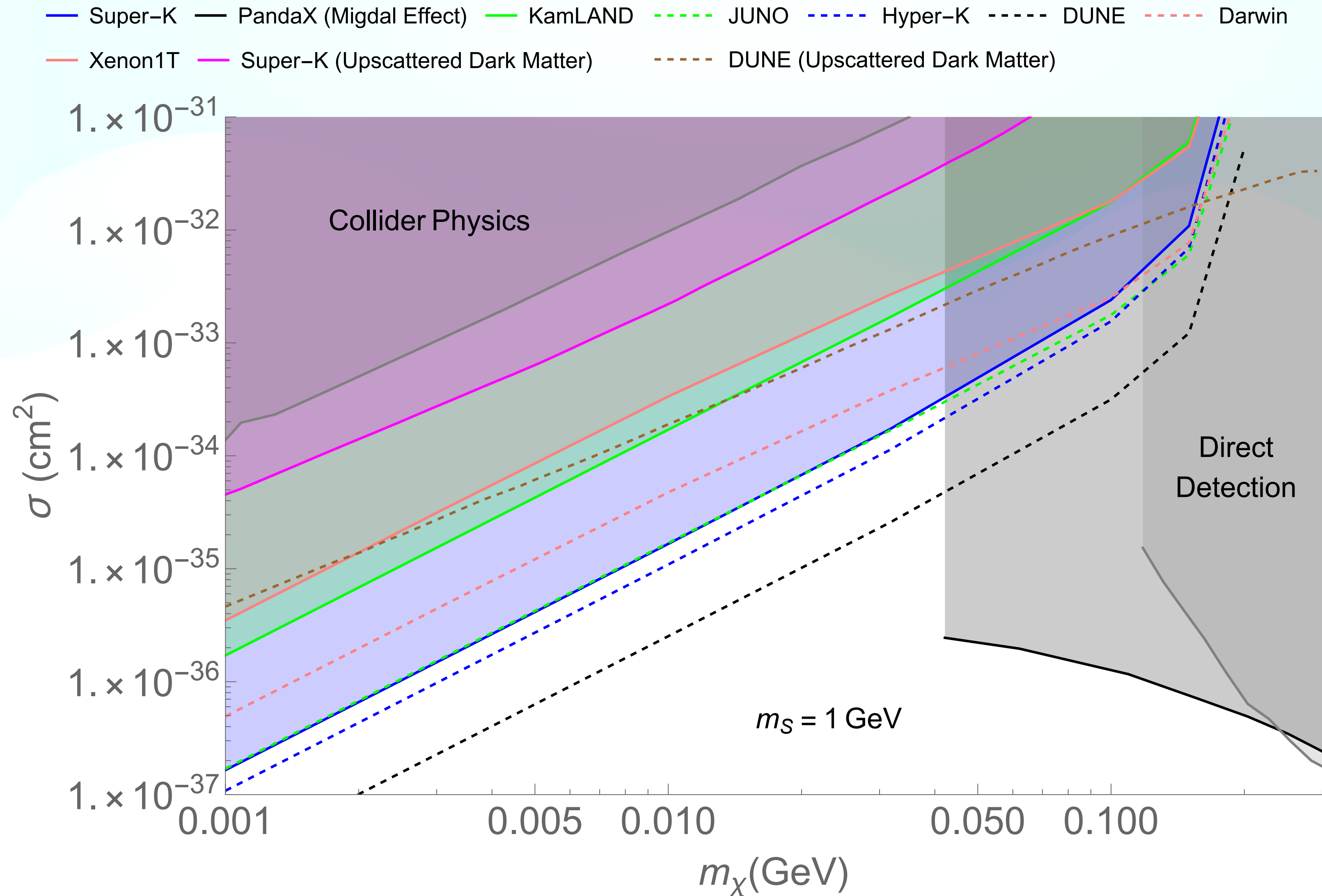
Solutions 1&2, current limits



This Talk: ... to this



This Talk: ... to this with 2 ideas



New Idea for Direct Detection

High-velocity DM component unavoidably generated by **Cosmic-ray scatterings**



Bringmann Pospelov 1810.10543

Ema FS Sato 1811.00520

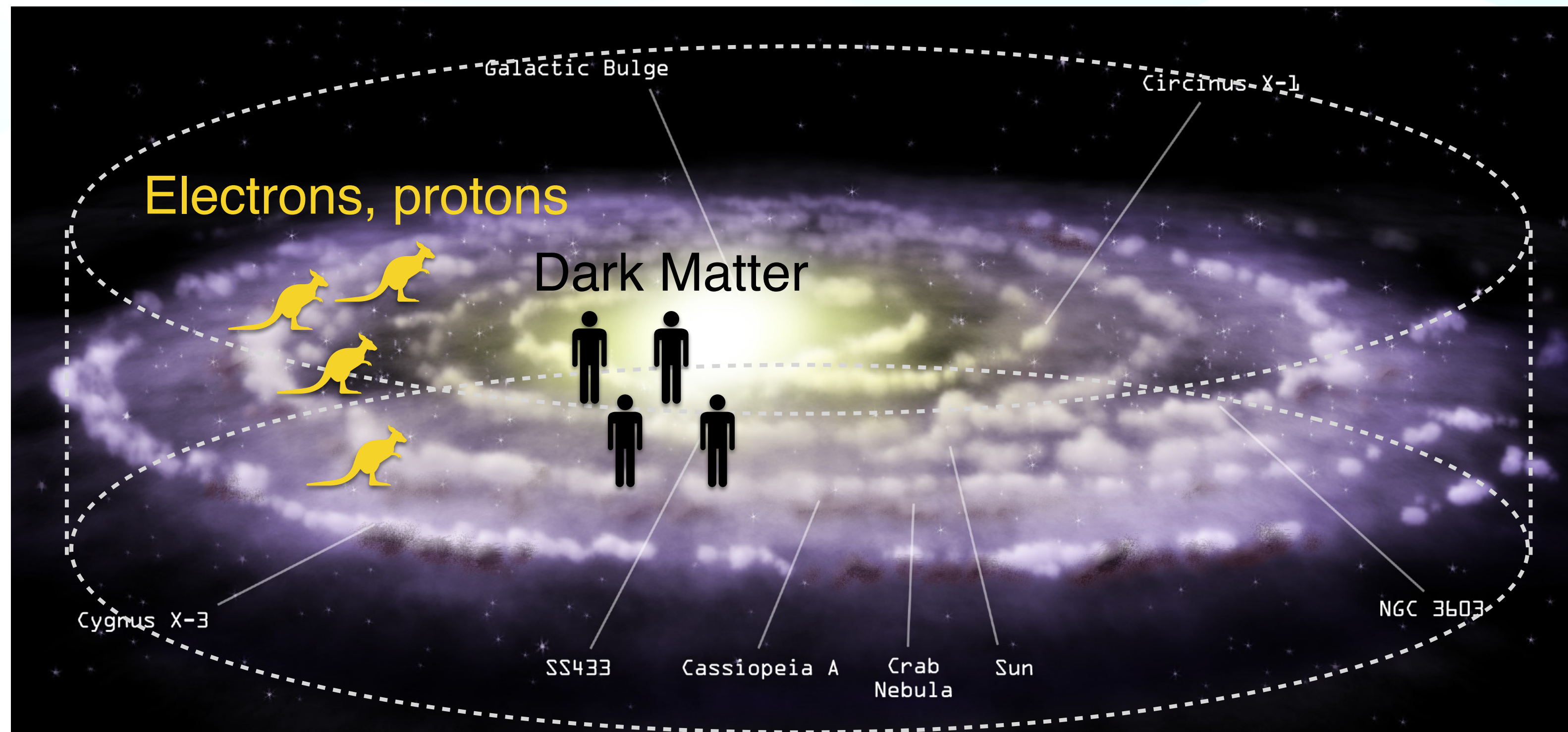


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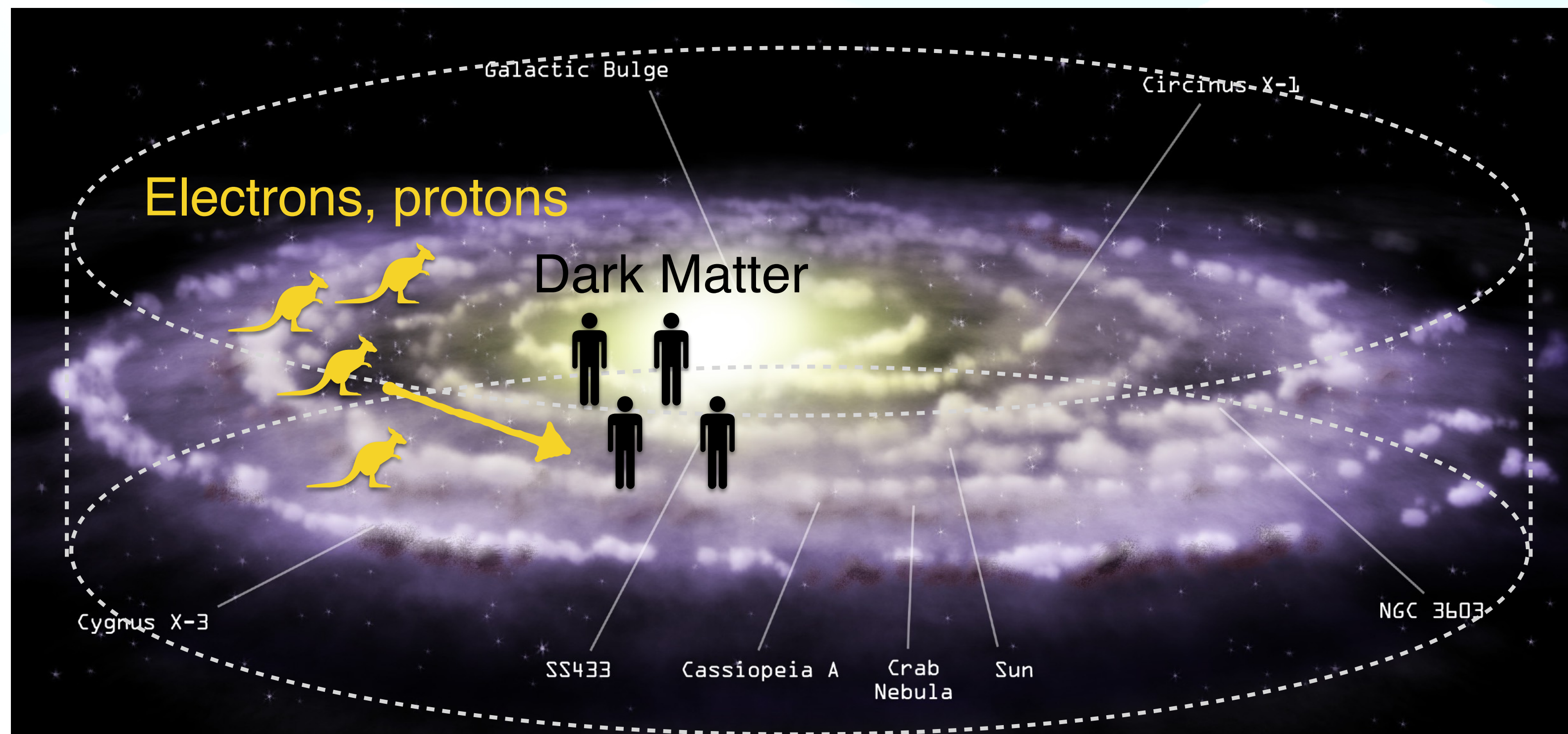


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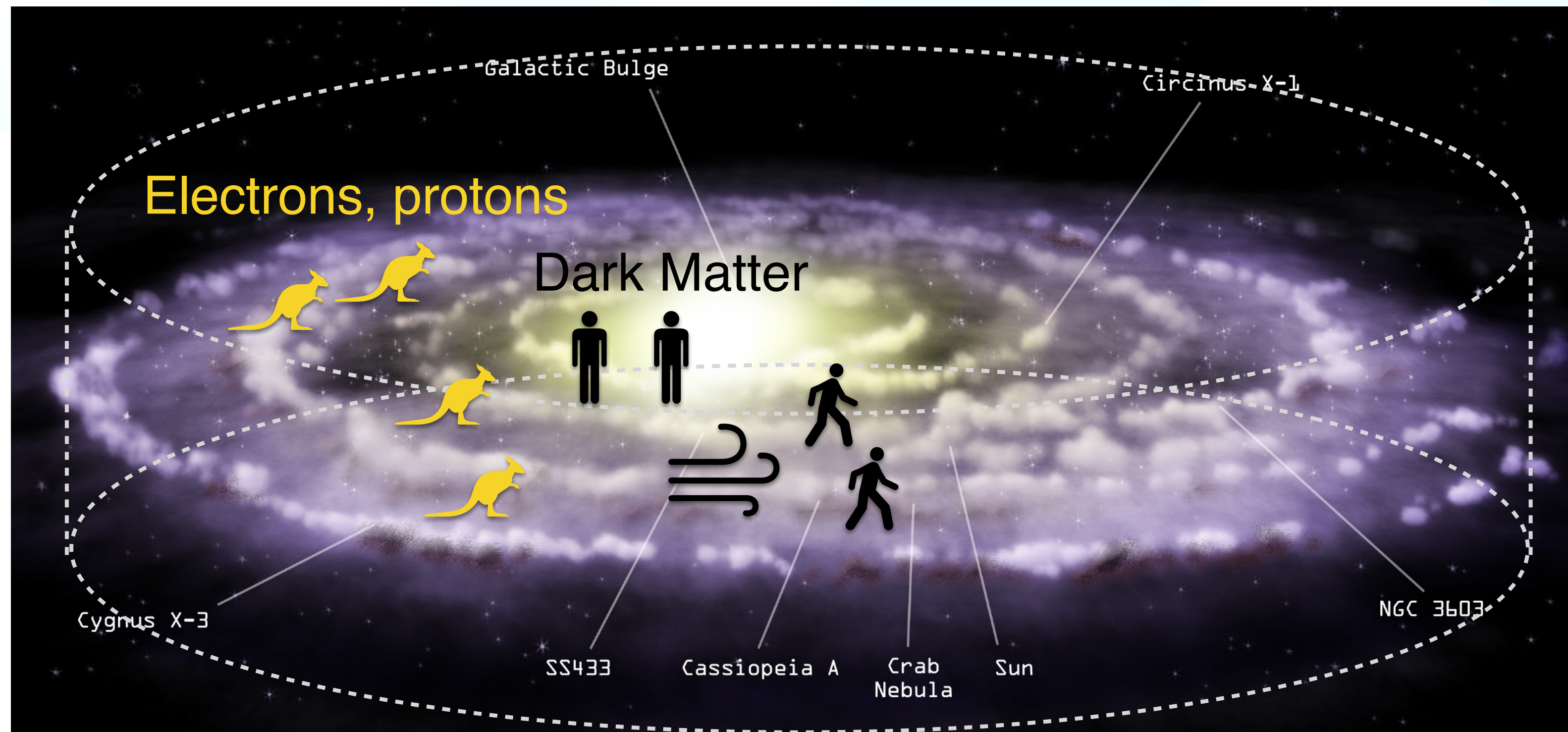


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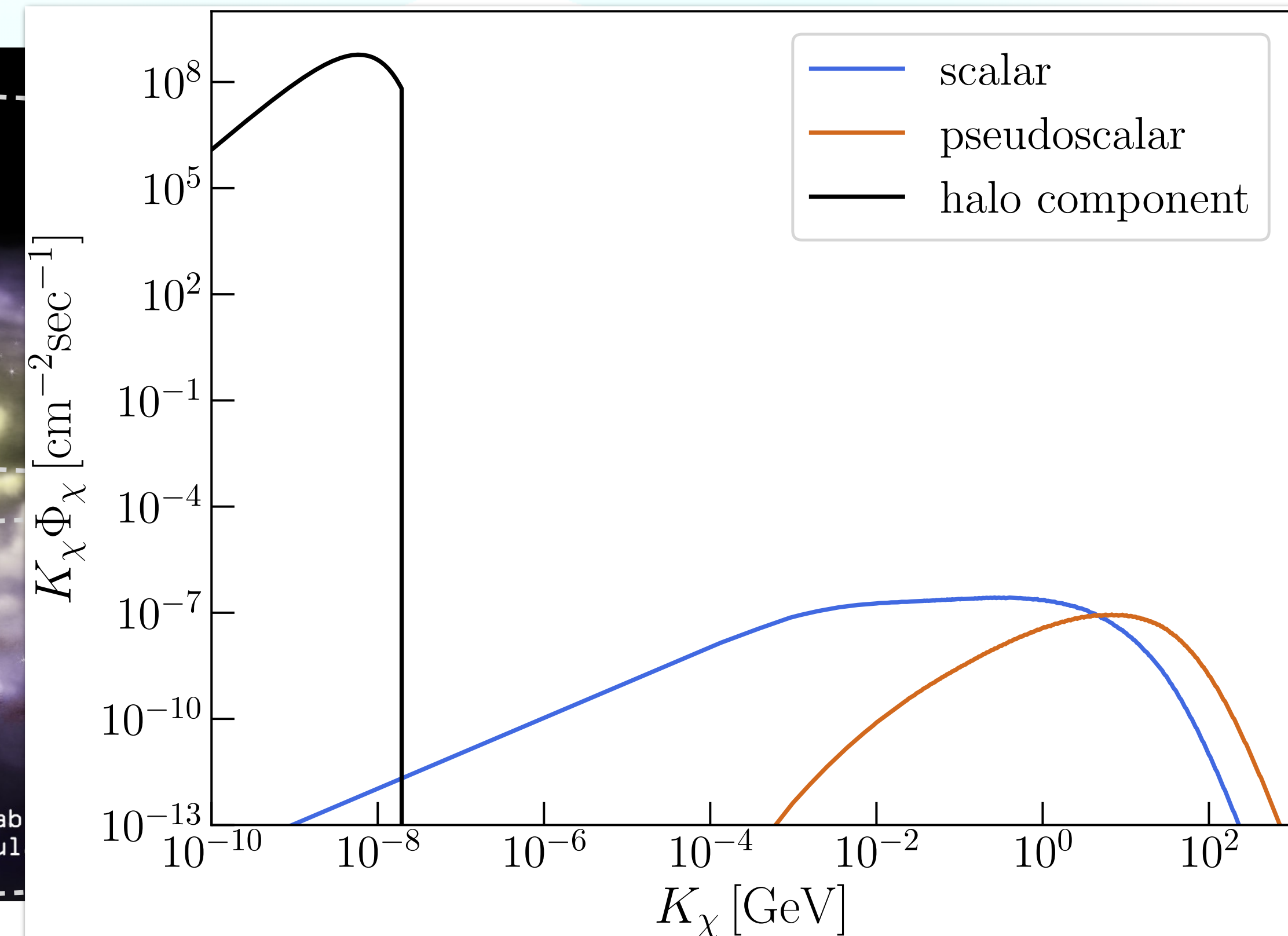
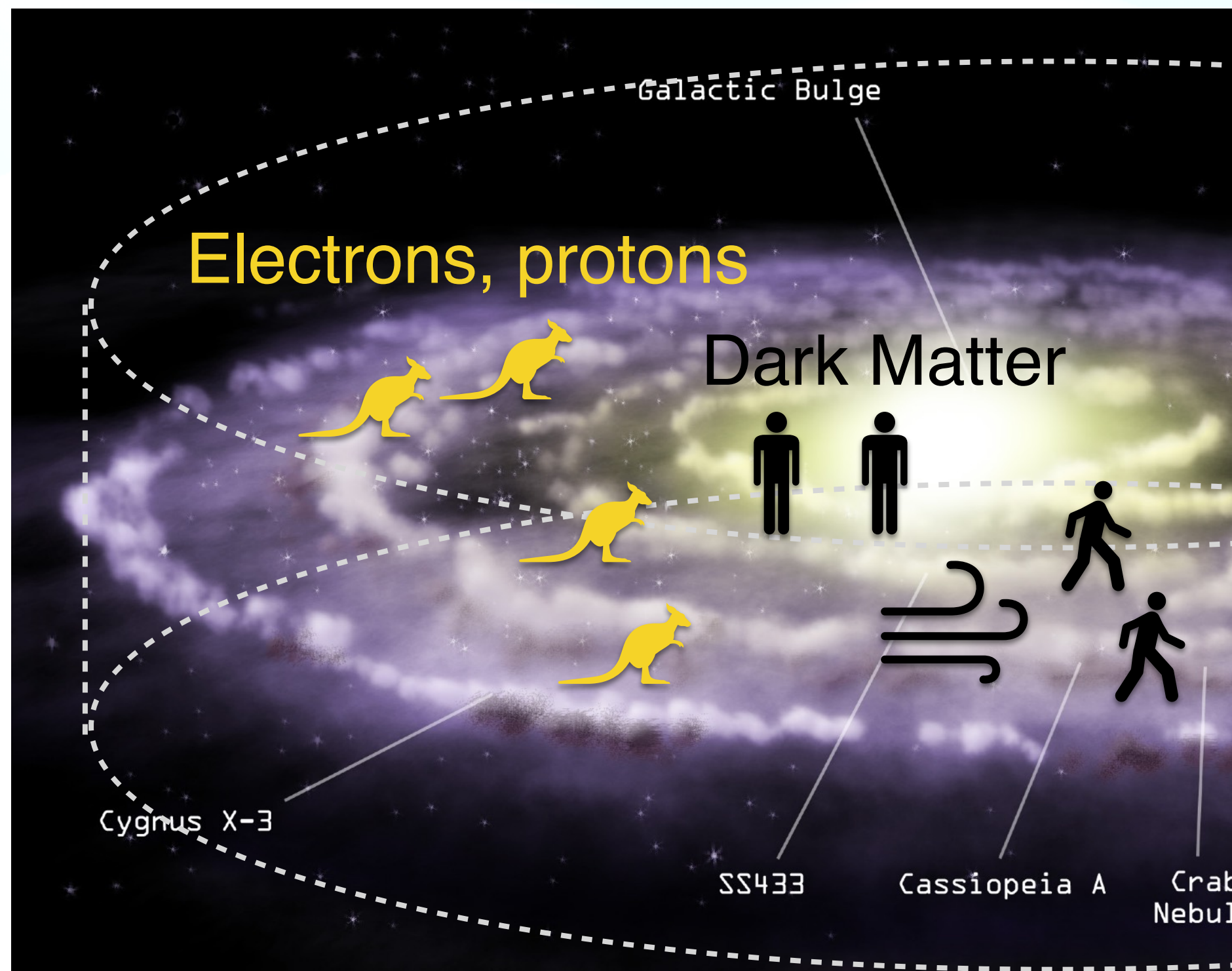


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$$M_{\text{DM}} = 10 \text{ MeV}, \quad M_{\text{mediator}} = \text{GeV}, \quad g_\chi g_u = g_\chi g_d = 0.1$$

New Idea for Direct Detection

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High-velocity DM component unavoidably generated by **Cosmic-ray scatterings**

Also by **Solar Upscattering**

An Pospelov Pradler Ritz+ 1708.03642

Emken Kouvaris Nielsen 1709.06573

Pueh Leng Tan @ this conf

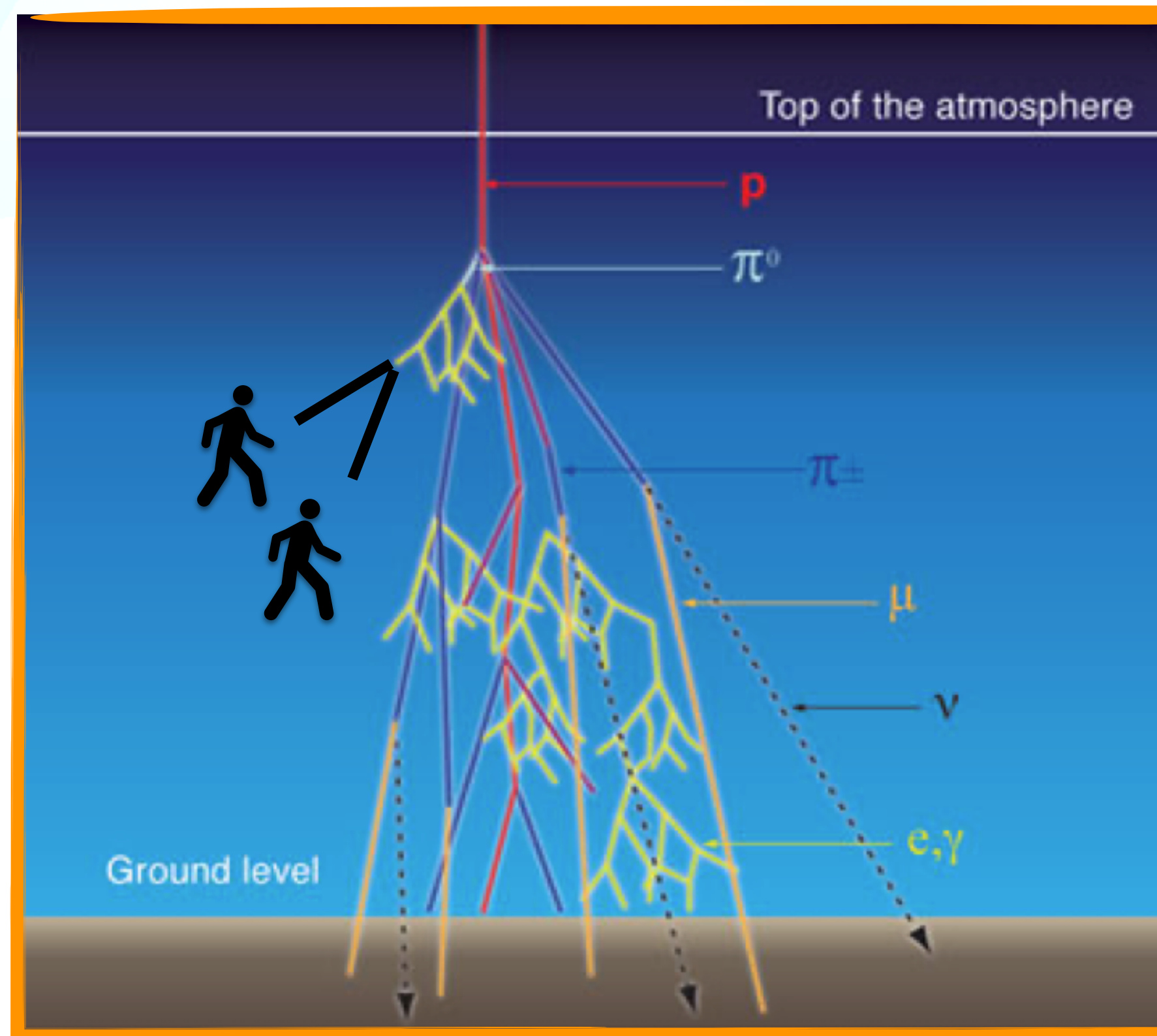


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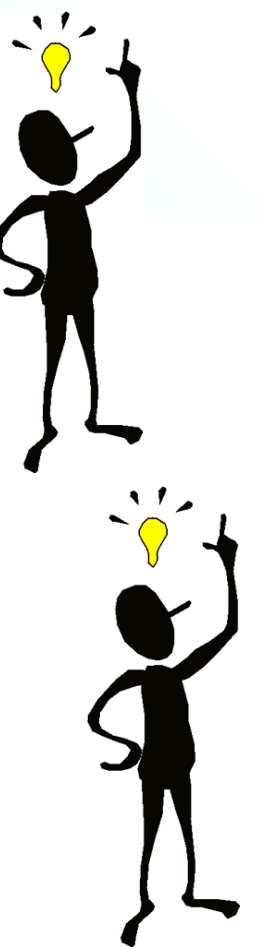
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Also by **Atmospheric Showers**

Alvey+ 1905.05776 , ...

Pascoli FS Xotta in progress

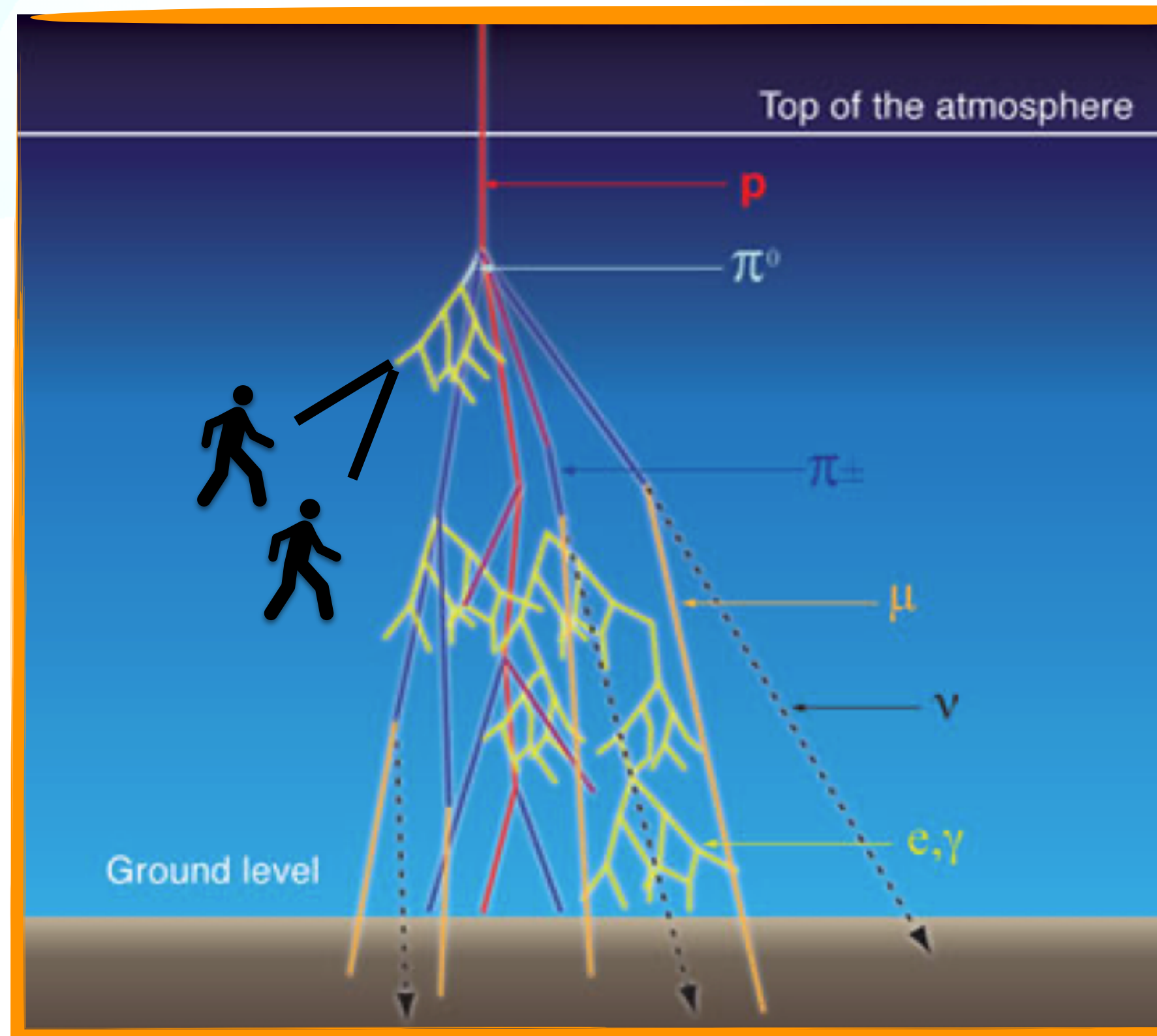


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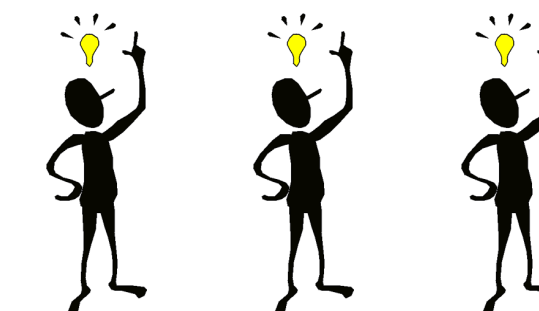
Alvey+ 1905.05776 , ...

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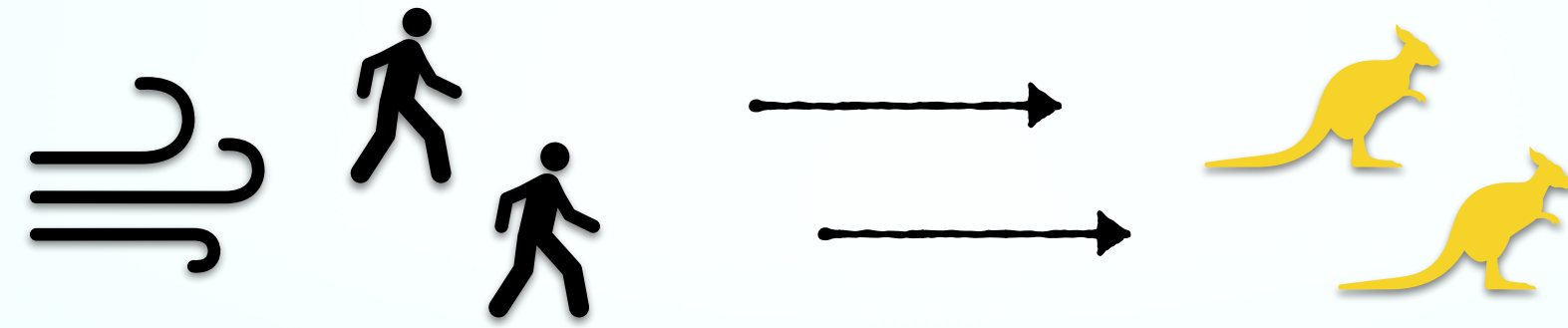
Also by **Blazars**

Wang Granelli Ullio 2111.13644, ...

Also by ...

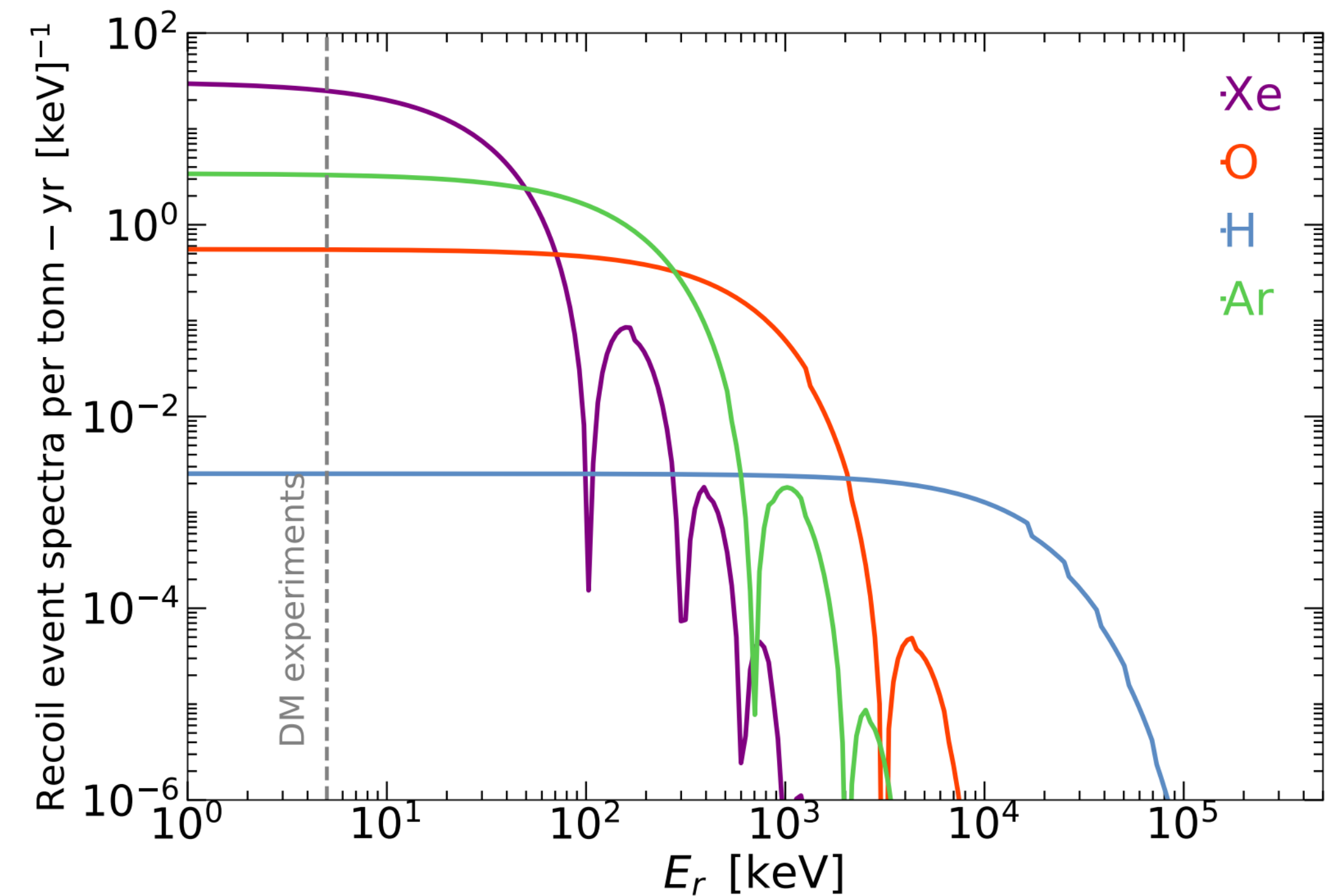
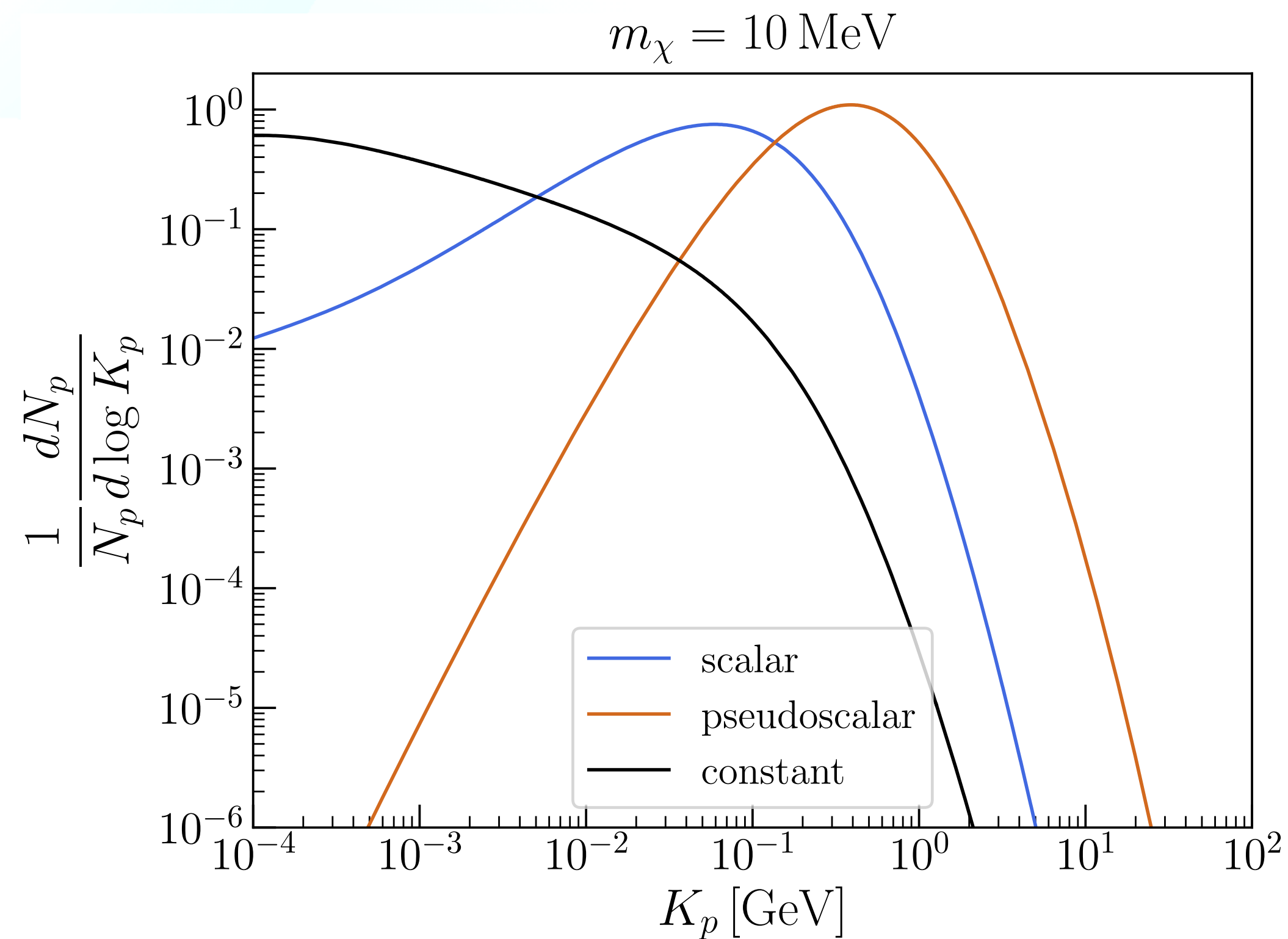


Recoil Spectra from fast Sub-GeV DM



From **Cosmic Rays**, Ema FS Sato 2011.01939

From **Atmosphere**, Arguelles+ 2203.12630



New Idea 2: use Neutrino Detectors



Recoil Energies $> 10 \text{ MeV}$  go to biggest existing detectors!

Ema FS Sato 1811.00520 CR-upscattered DM, electrons

Ema FS Sato 2011.01939 CR-upscattered DM, nucleons

Pascoli FS Xotta in progress Atmospheric DM, nucleons

New Idea 2: use Neutrino Detectors

Ema FS Sato 2011.01939 CR-upscattered DM, nucleons

CR-DM vs nucleons at Neutrino Experiments

Protons with $p_p > 1.07$ GeV emit Cherenkov light, already used for ν 's in [Super-K 0901.1645](#)

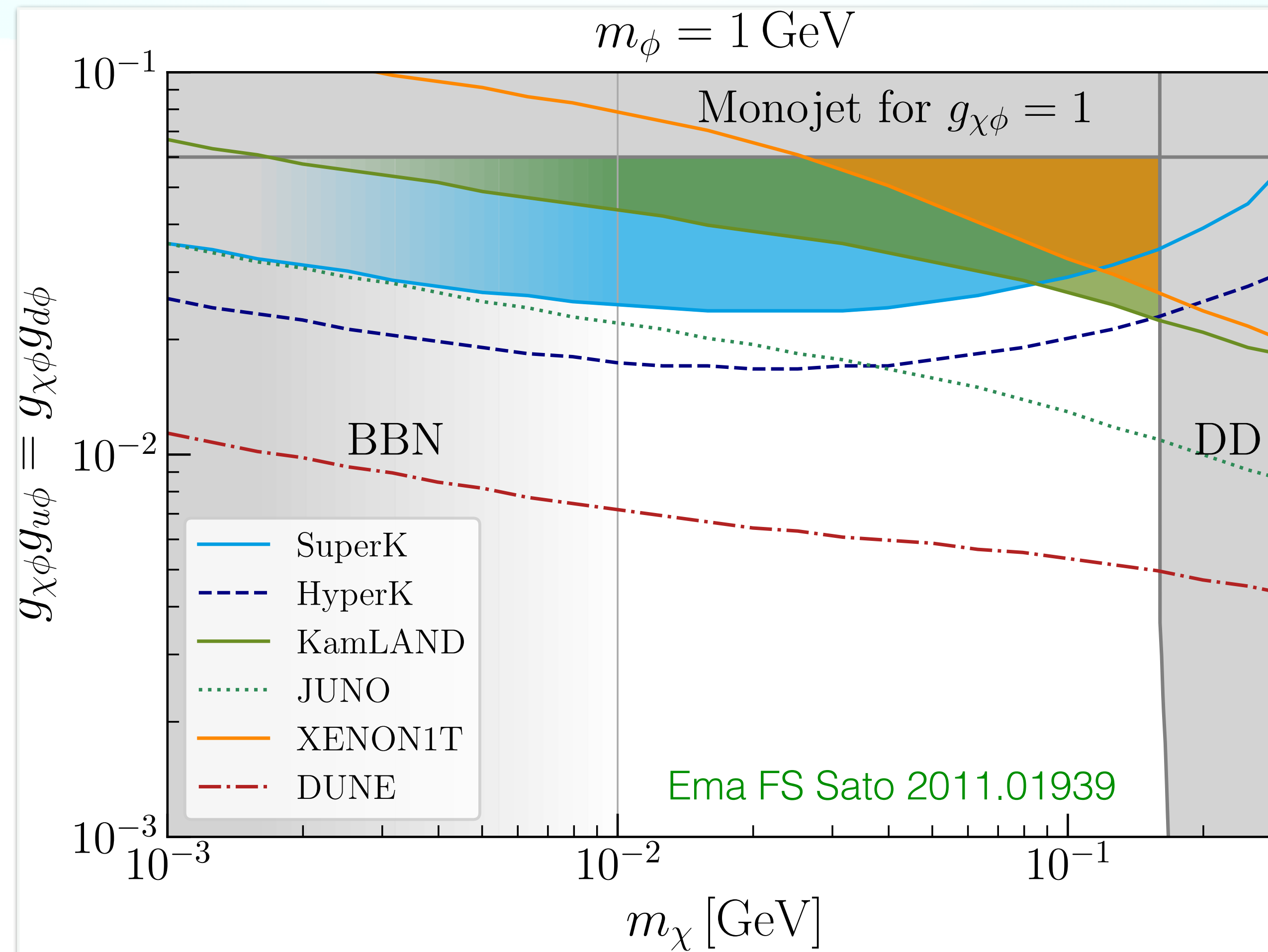
We repurposed it!

CR-DM vs nucleons at Neutrino Experiments

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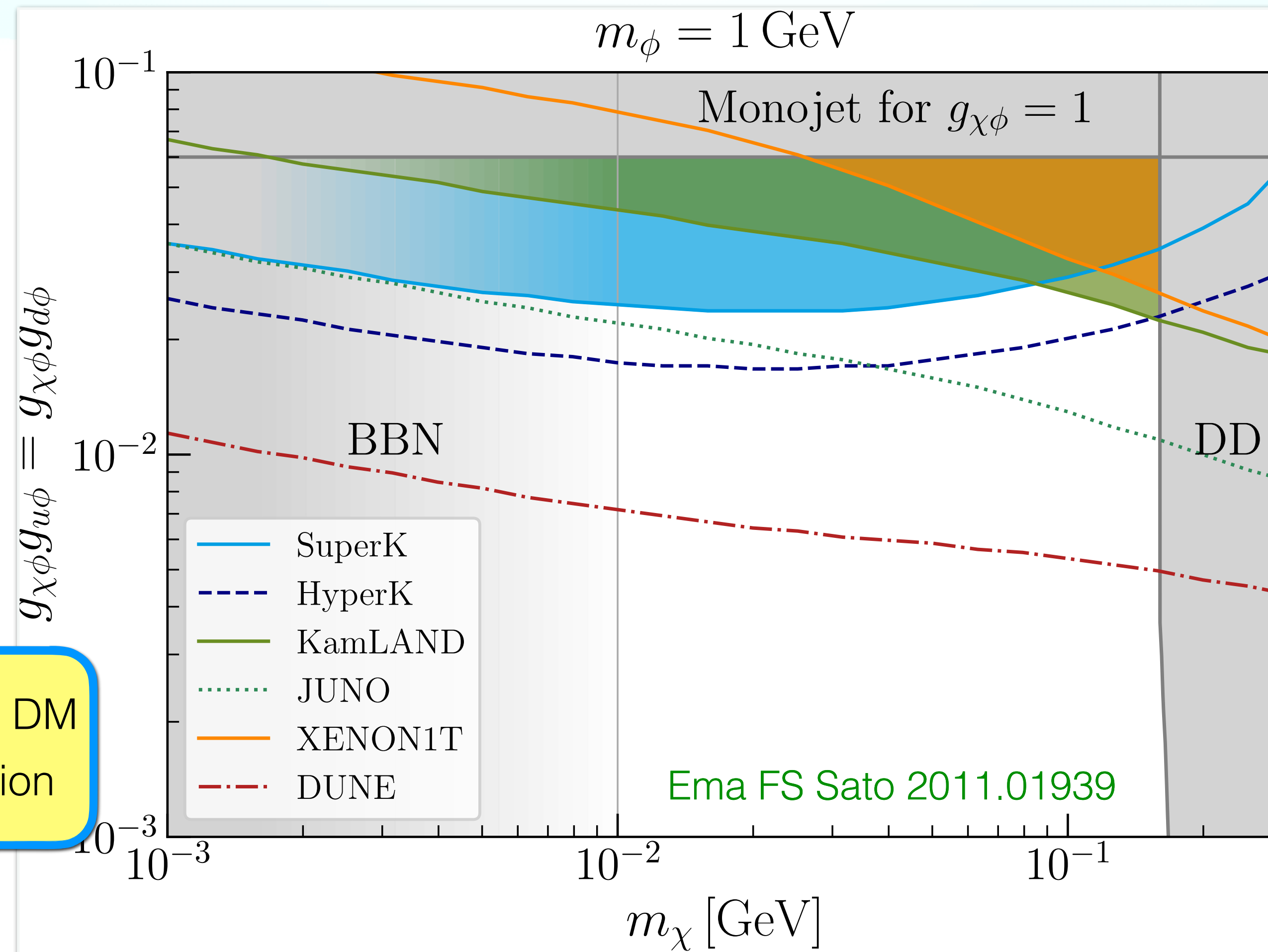
$$\mathcal{L} \supset g_\chi \phi \bar{\chi} \chi + g_q \phi \bar{q} q$$



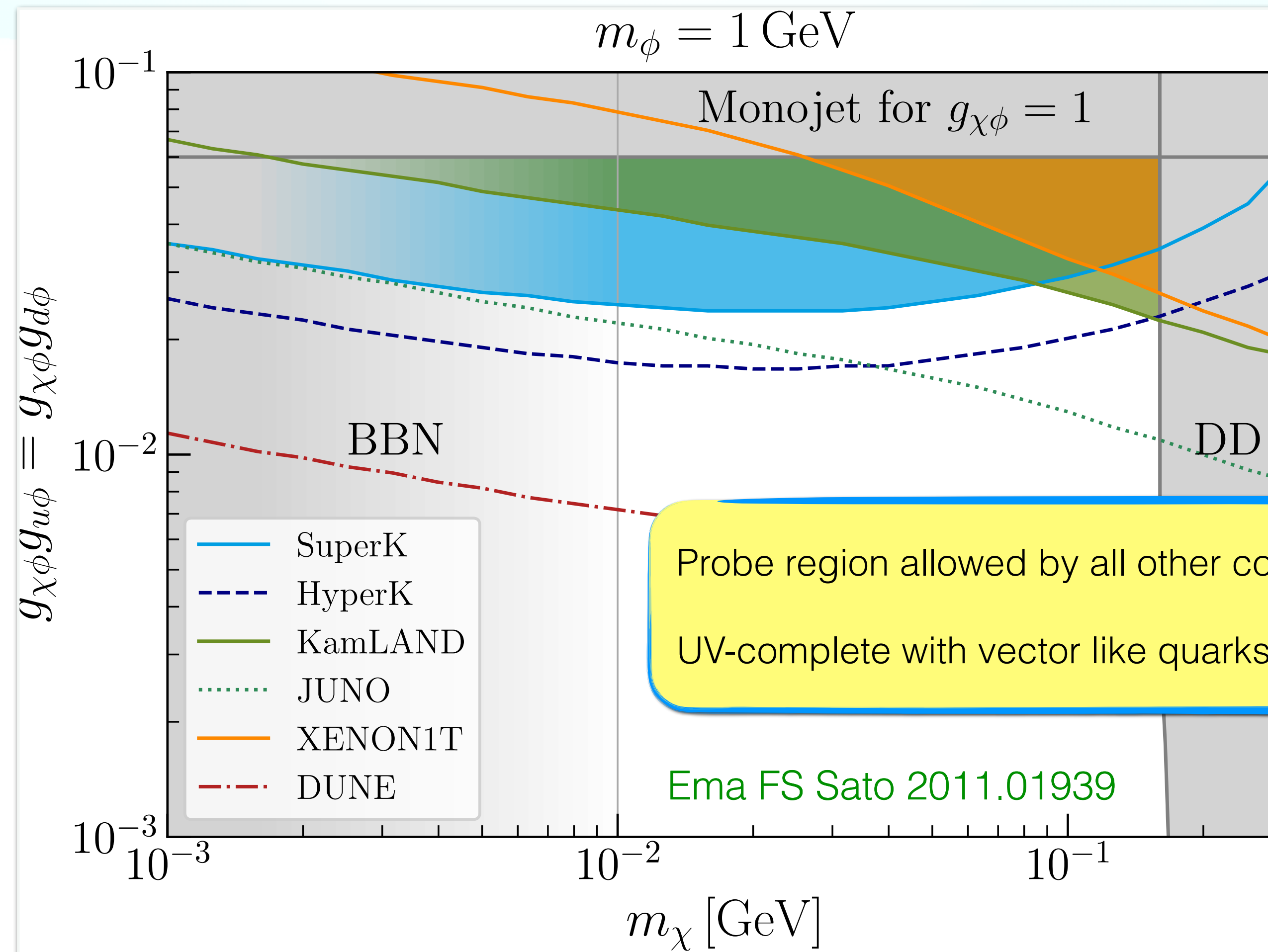
CR-DM vs nucleons at Neutrino Experiments

$$\mathcal{L} \supset g_\chi \phi \bar{\chi} \chi + g_q \phi \bar{q} q$$

These ideas test also inelastic DM
unlike 'standard' direct detection



CR-DM vs nucleons at Neutrino Experiments

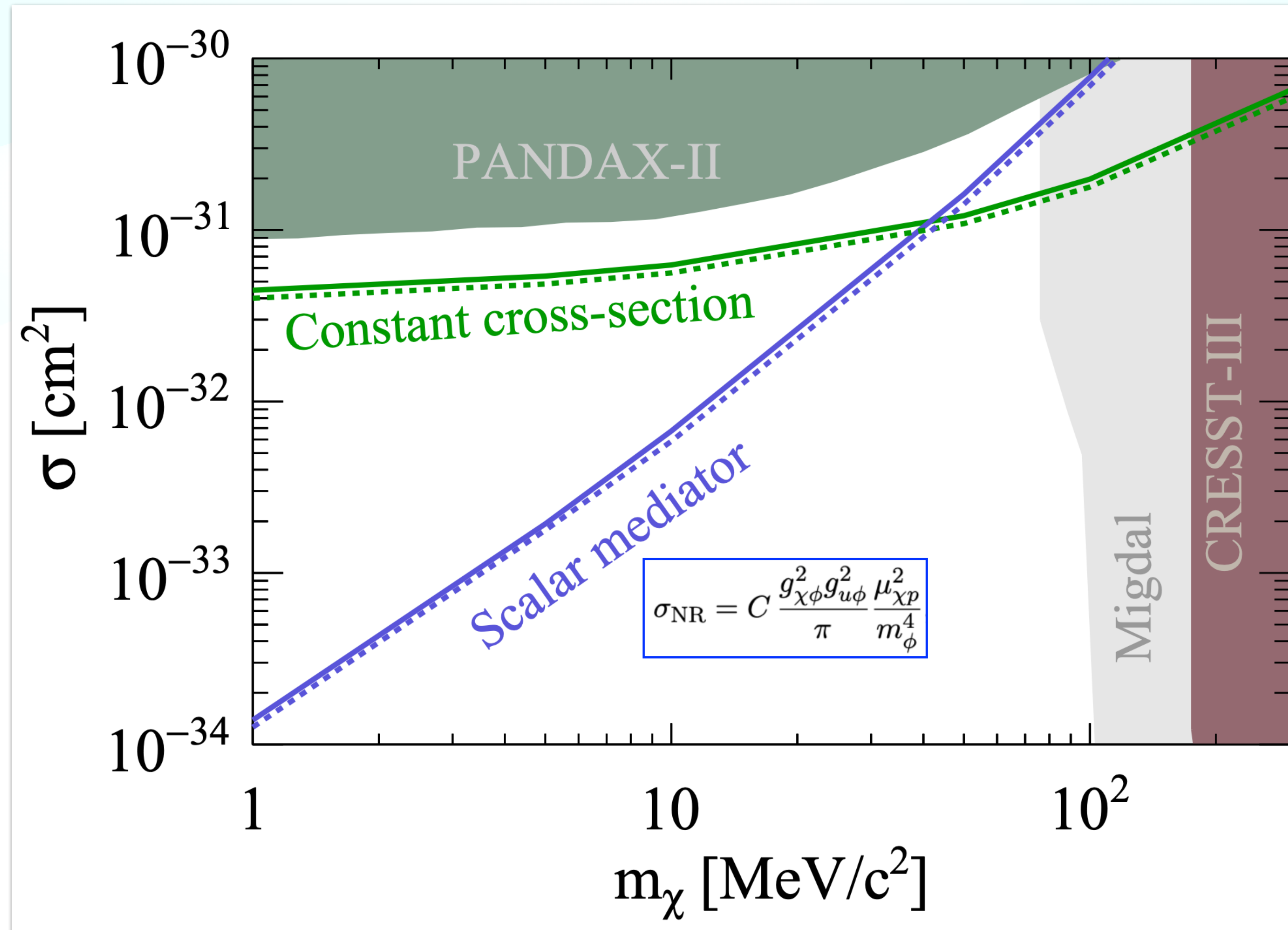


Experimentalist
from Super-K, DUNE...



Super-K then did the search!

Super-K 2209.14968



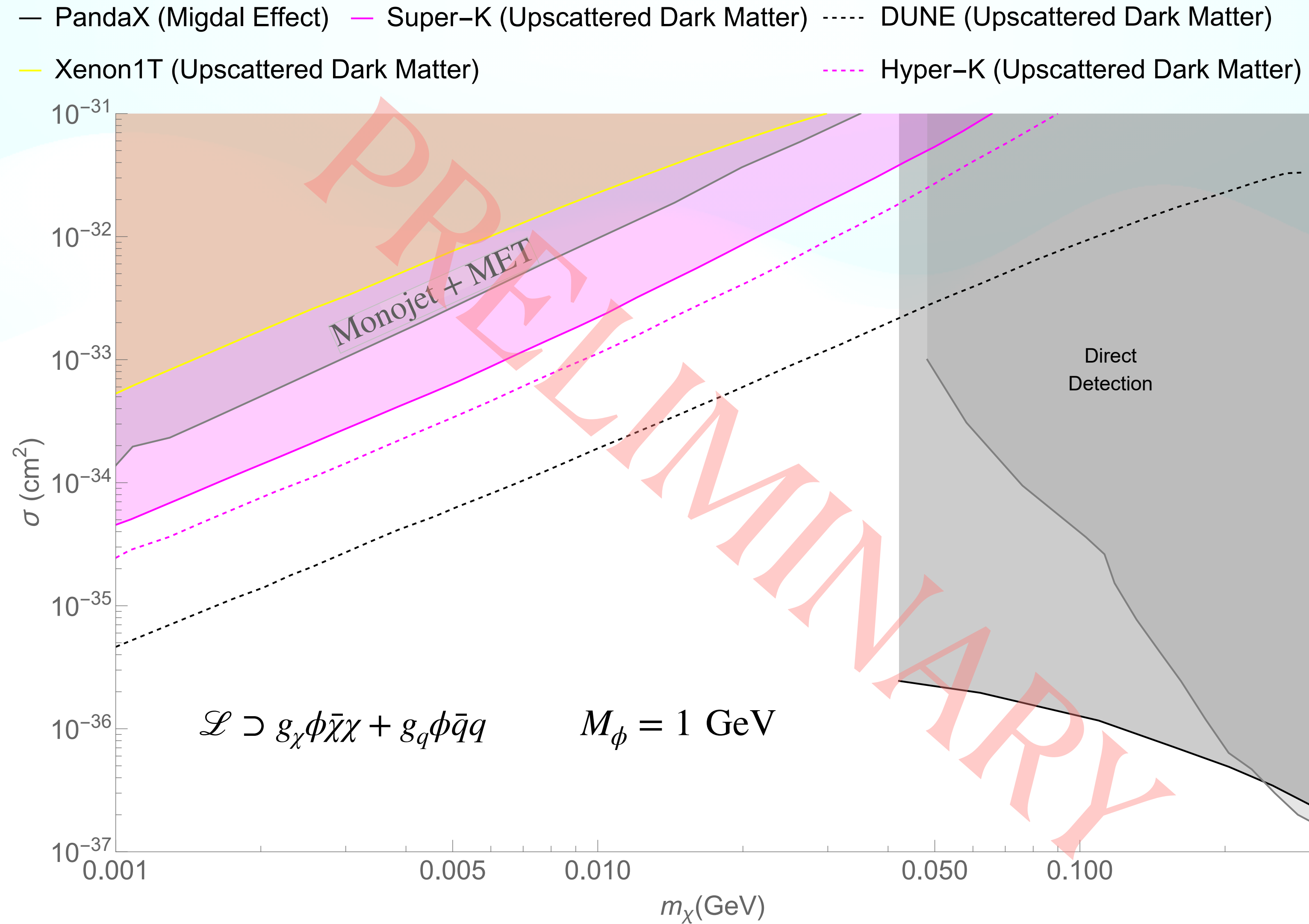
New Idea 2: use Neutrino Detectors

Ema FS Sato 2011.01939 CR-upscattered DM, nucleons

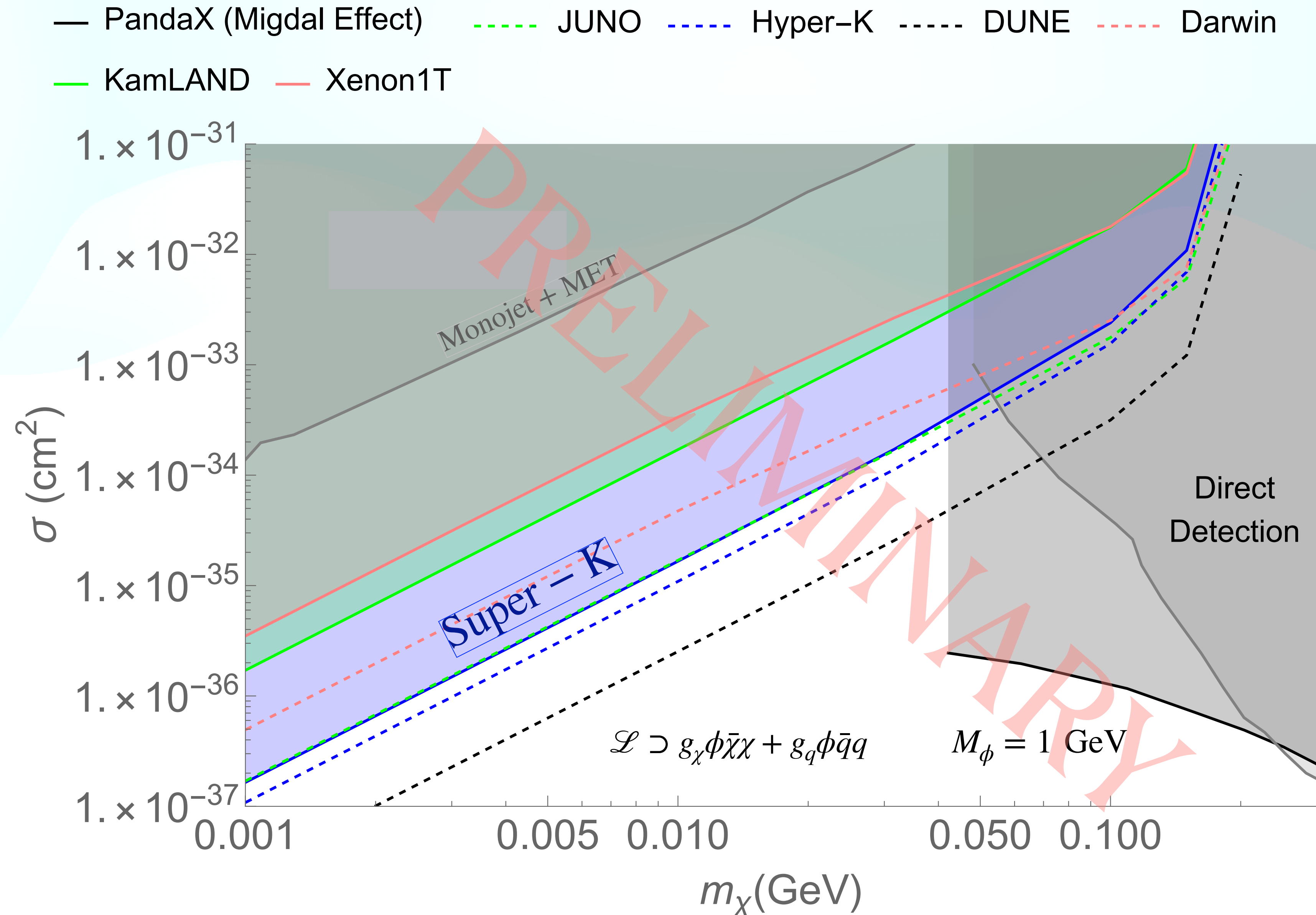
New Idea 2: use Neutrino Detectors

Pascoli FS Xotta in progress Atmospheric DM, nucleons

From Neutrino Detectors & CR-DM



To Neutrino Detectors & Atmospheric DM



Pascoli FS Xotta in progress
only DM from eta mesons

Summary: Fast DM + Neutrino Detectors =



Detection at IceCube & KM3NeT?

Outlook: Full simulation of DM from Atmosphere?

Other sources of fast DM?

...

Back up

More on: DM-nucleon scatterings

Cross Sections

$$\mathcal{L} \supset g_\chi a \bar{\chi} i \gamma_5 \chi + g_q a \bar{q} i \gamma_5 q$$

$$\frac{d\sigma_a}{dK_f} = \frac{1}{K_{\max}} \frac{g_{\chi a}^2 g_{Na}^2}{16\pi s} \frac{t^2}{(m_a^2 - t)^2} F_a^2(-t)$$

$$F_a(q^2) = G_a^{u+d}(q^2)$$

PCAC relation

$$G_a^q(-t) = G_A(-t) + \frac{t}{4m_N^2} G_P^q(-t) - 2\epsilon_q G_G(-t)$$

$$g_{Na} = g_a \frac{2m_N}{m_u + m_d} h_{u+d}$$

$$g_{ua} = g_{da} = g_a$$

$$h_q = \frac{\langle N | m_q \bar{q} i \gamma_5 q | N \rangle}{m_N}$$

$$h_{u+d} = 0.45$$

$$\mathcal{L} \supset g_\chi S \bar{\chi} \chi + g_q S \bar{q} q$$

$$\frac{d\sigma_\phi}{dK_f} = \frac{1}{K_{\max}} \frac{g_{\chi\phi}^2 g_{N\phi}^2}{16\pi s} \frac{(-t + 4m_\chi^2)(-t + 4m_A^2)}{(m_\phi^2 - t)^2} n_A^2 F_A^2(-t)$$

$$F_{\text{He}}(q^2) = \frac{1}{(1 + q^2/\Lambda_{\text{He}}^2)^2}, \quad \Lambda_{\text{He}} = 410 \text{ MeV}$$

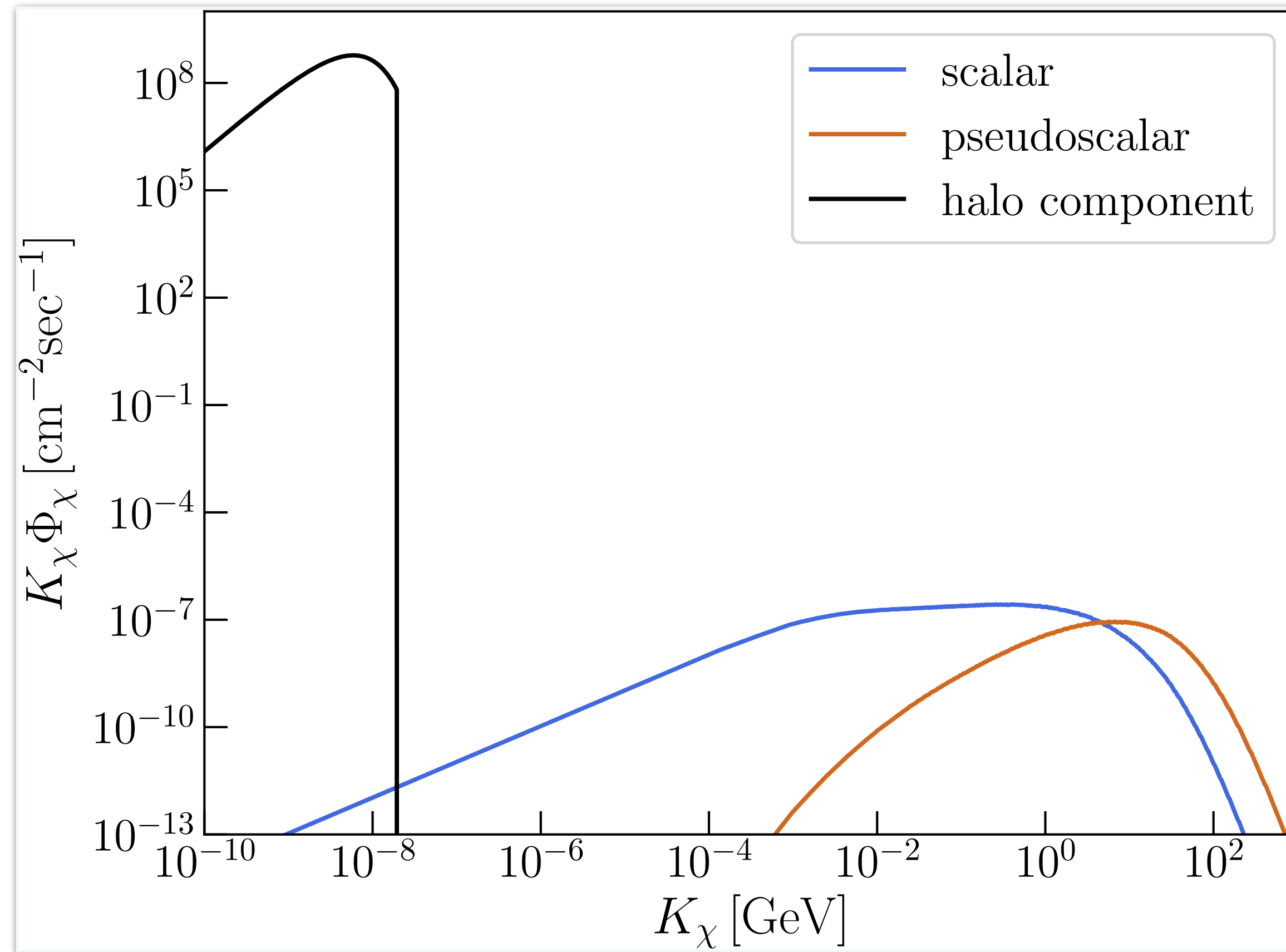
$$g_{N\phi} = g_\phi \left(\frac{m_N}{m_u} f_u^N + \frac{m_N}{m_d} f_d^N \right)$$

$$g_{u\phi} = g_{d\phi} = g_\phi$$

$$f_q^N = \frac{\langle N | m_q \bar{q} q | N \rangle}{m_N}$$

$$f_u^N = 1.99 \times 10^{-2}, \quad f_d^N = 4.31 \times 10^{-2},$$

Flux of Accelerated DM Component



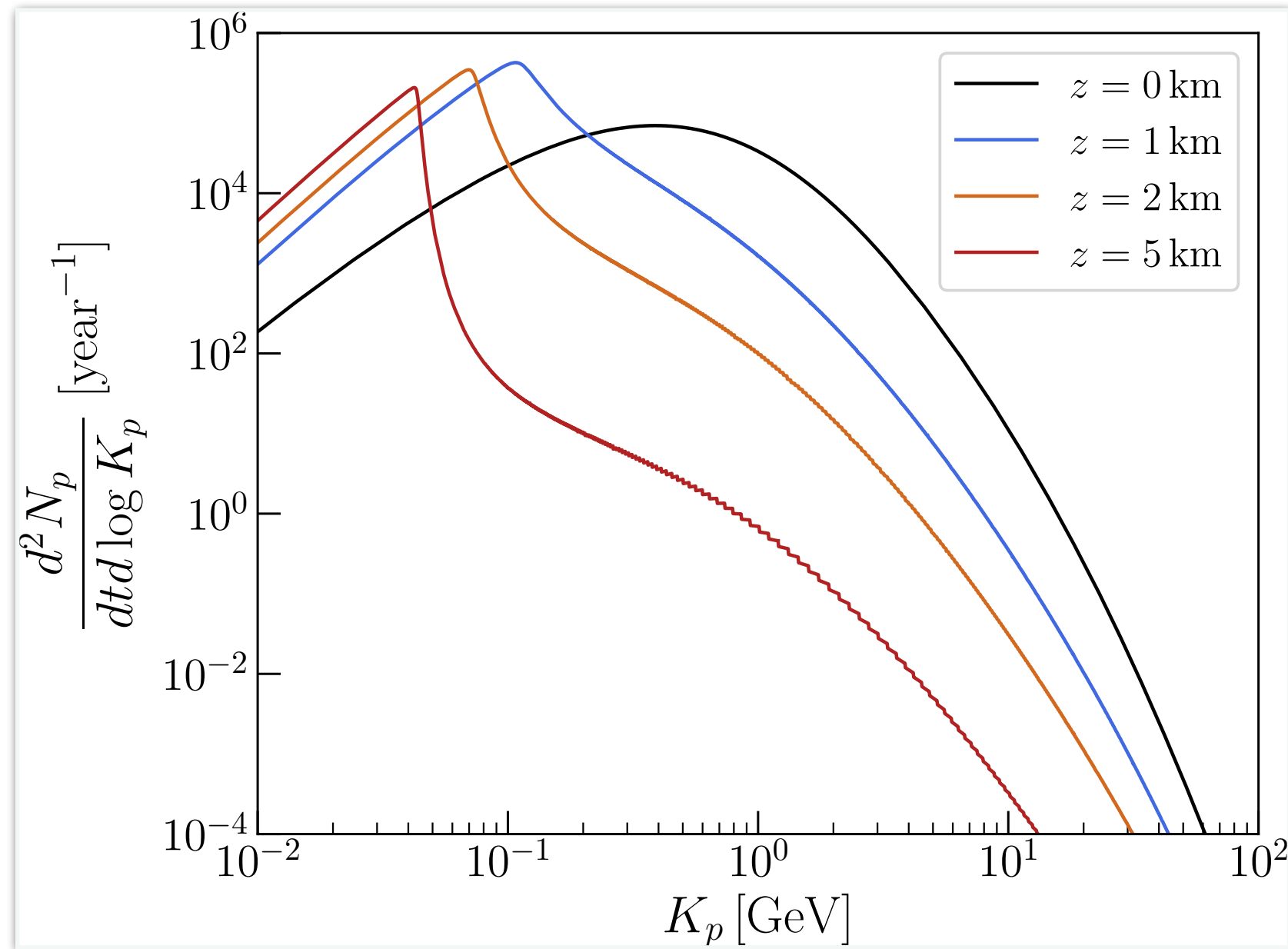
$$M_{\text{DM}} = 10 \text{ MeV}, \quad M_{\text{mediator}} = \text{GeV}, \quad g_\chi g_u = g_\chi g_d = 0.1$$

Earth Attenuation

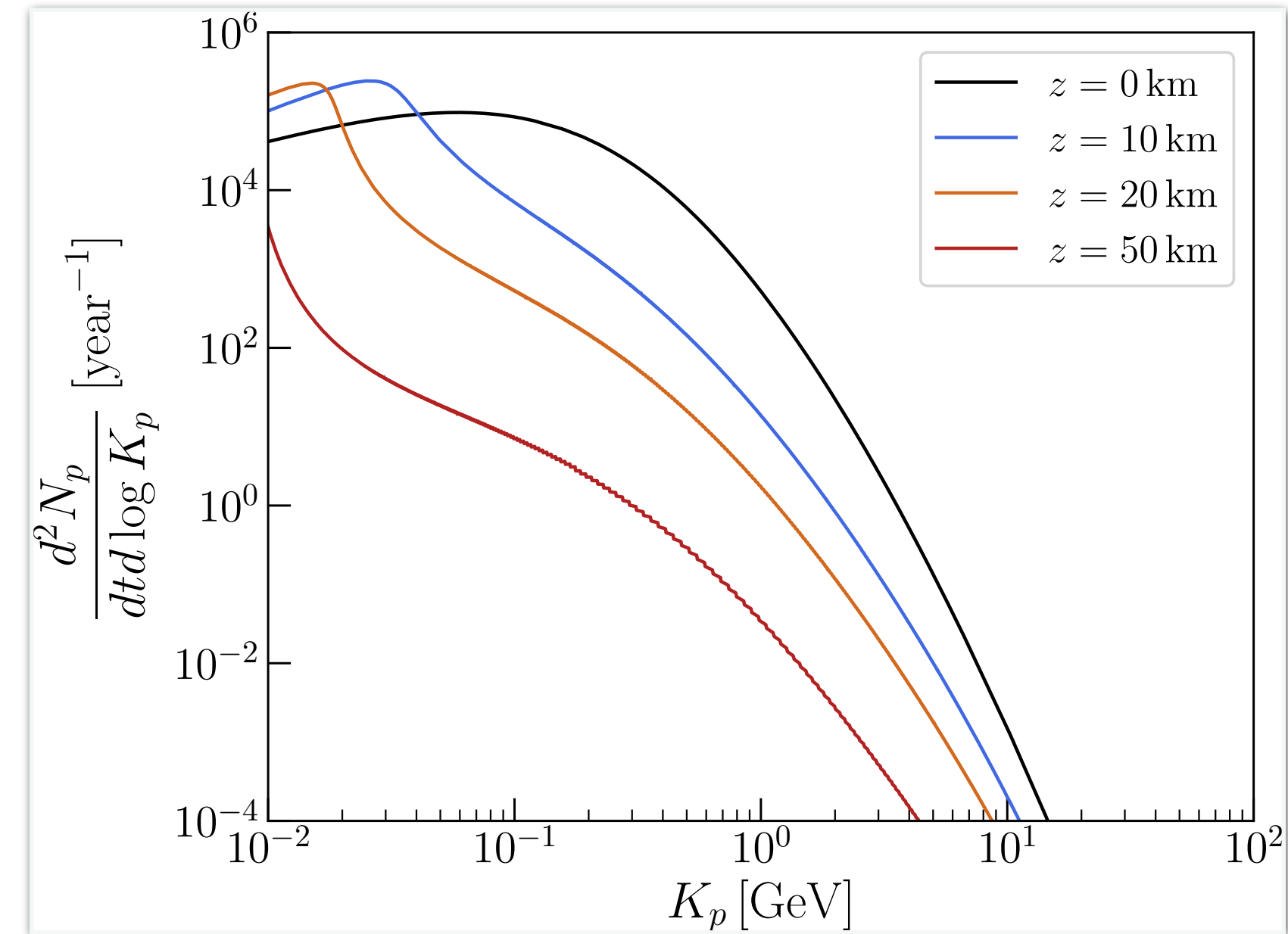
$$\frac{d\bar{K}_\chi(z)}{dz} = - \sum_T n_T \int dK_T K_T \frac{d\sigma}{dK_T}$$

$$\bar{\Phi}_\chi(z) d\bar{K}_\chi(z) = \Phi_\chi dK_\chi$$

$$\mathcal{L} \supset g_\chi a \bar{\chi} i \gamma_5 \chi + g_q a \bar{q} i \gamma_5 q$$



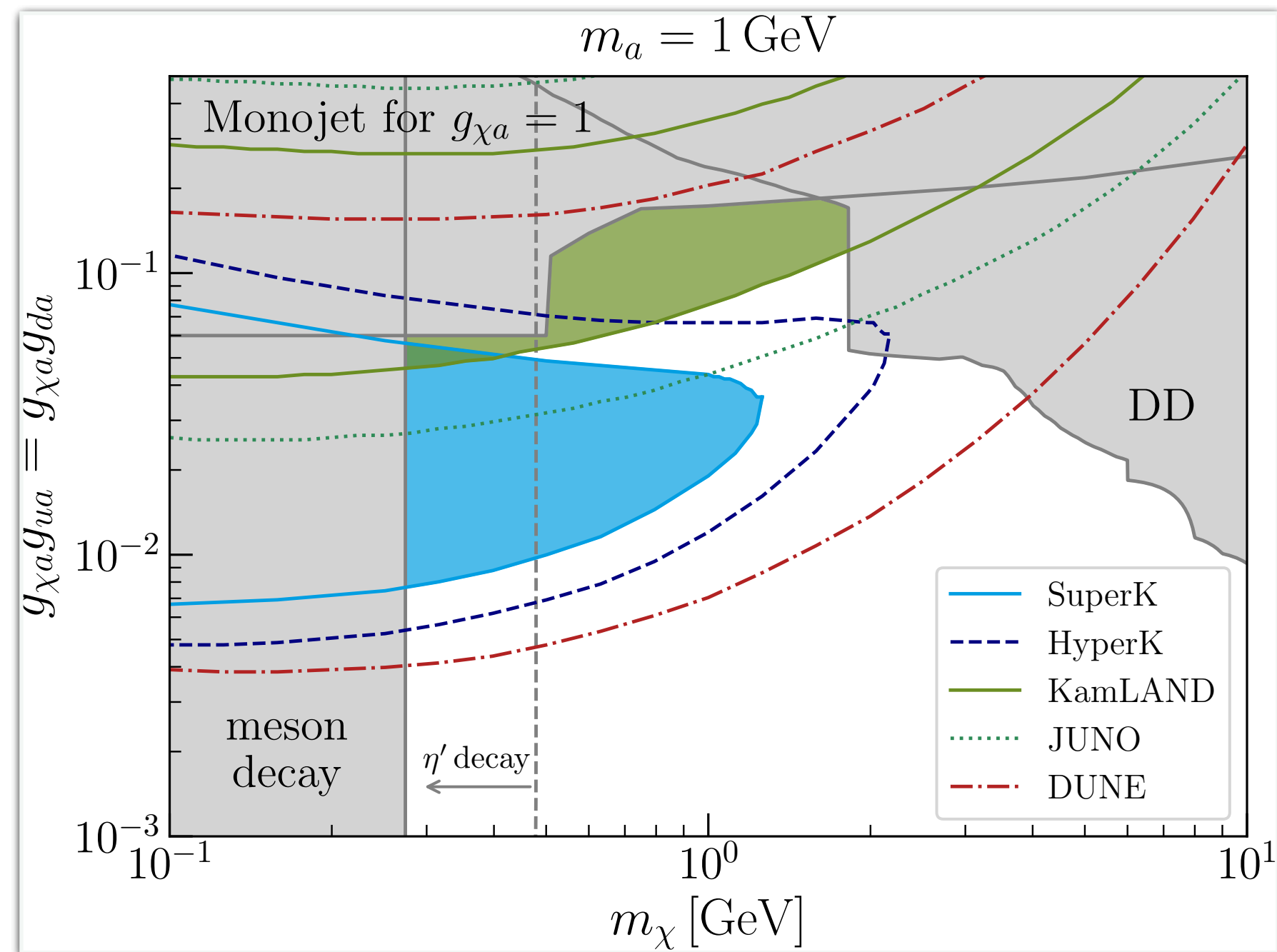
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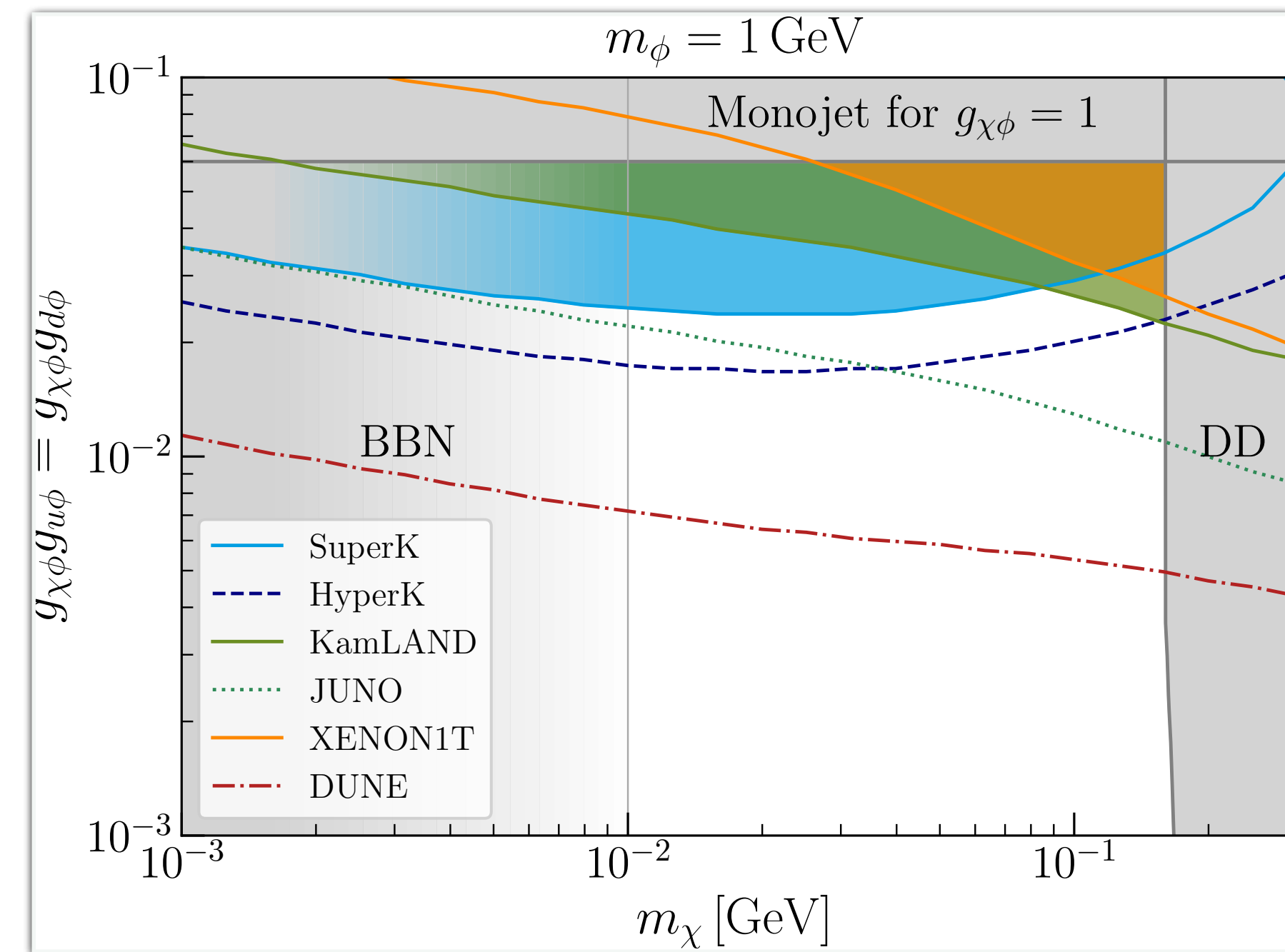
$$M_{\text{DM}} = 10 \text{ MeV}, \quad M_{\text{mediator}} = \text{GeV}, \quad g_\chi g_u = g_\chi g_d = 0.1$$

Limits for other values of parameters

$$\mathcal{L} \supset g_\chi a \bar{\chi} i \gamma_5 \chi + g_q a \bar{q} i \gamma_5 q$$

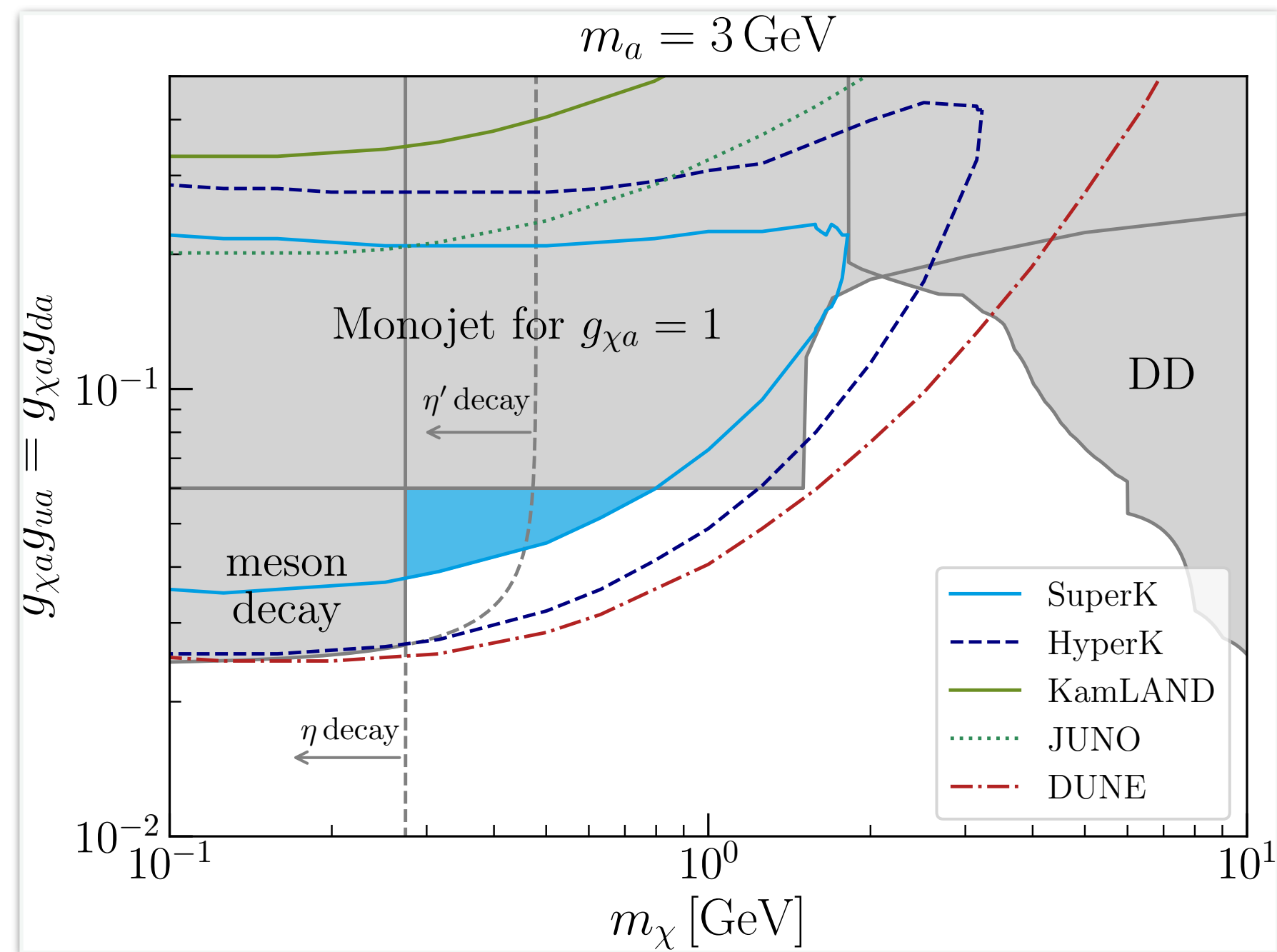


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Limits for other values of parameters

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$$\mathcal{L} \supset g_\chi S \bar{\chi} \chi + g_q S \bar{q} q$$

