Precision and intensity probes of new physics

Yotam Soreq

Planck 2025, Padova, May 30, 2025

standard model

standard model

feebly interacting spin 0

hidden sector

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hidden sector

- **naturally predicted** in many extensions of the standard model

standard model

feebly interacting spin 0

hidden sector

- naturally predicted in many extensions of the standard model
- associated with solutions to fundamental problems:
  strong CP, dark matter, hierarchy problems

Peccei, Quinn 77; Weinberg 78; Wilczek 78
Preskill, Wise 83; Abbott, Sikivie 83; Dine, Fleischer 83
Graham, Kaplan, Rajendran 15
+ many many more

Feebly interacting new spin-0

- limiting cases of the theory (flavor diagonal):

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  - Higgs mixing (CP even)

Feebly interacting new spin-0

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  - general flavor aligned (CP even) Delaunay, Kitahara, YS, Zupan, 2501.16477

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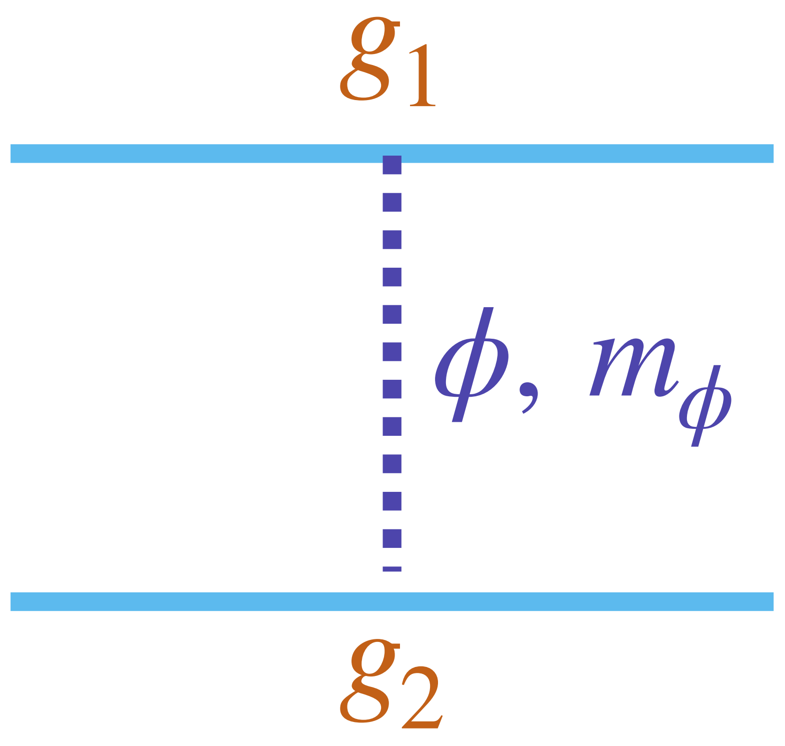
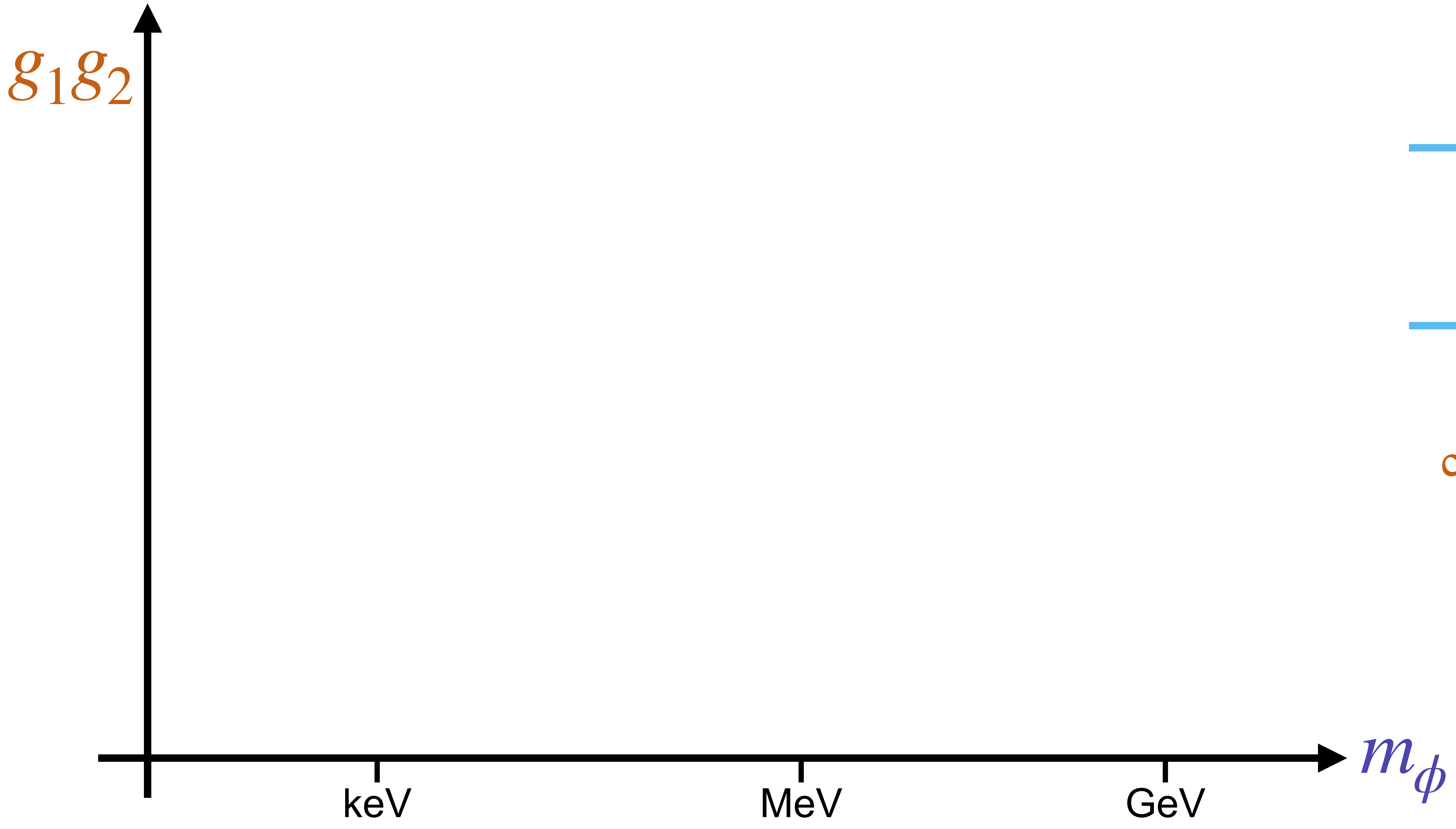
this talk:
spectroscopy vs Kaon decay
future probes

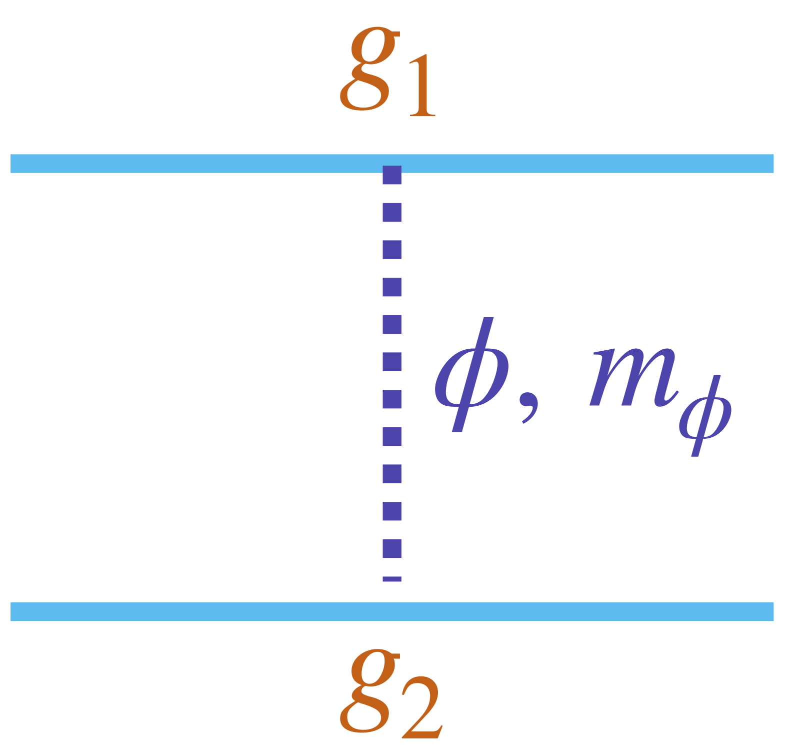
CP even: spectroscopy



$$\propto g_1 g_2 \frac{e^{-m_\phi r}}{r}$$

CP even: spectroscopy





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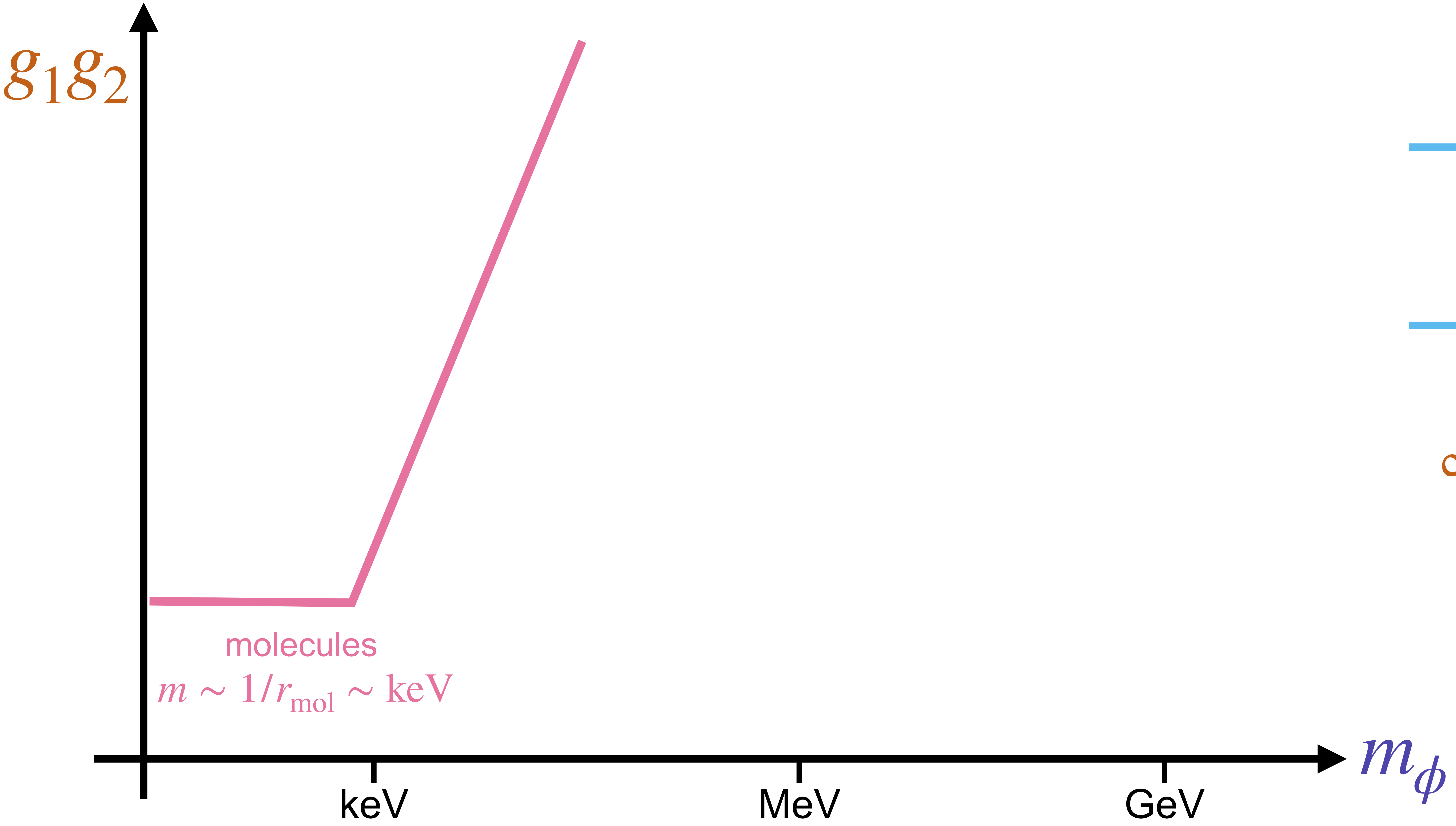

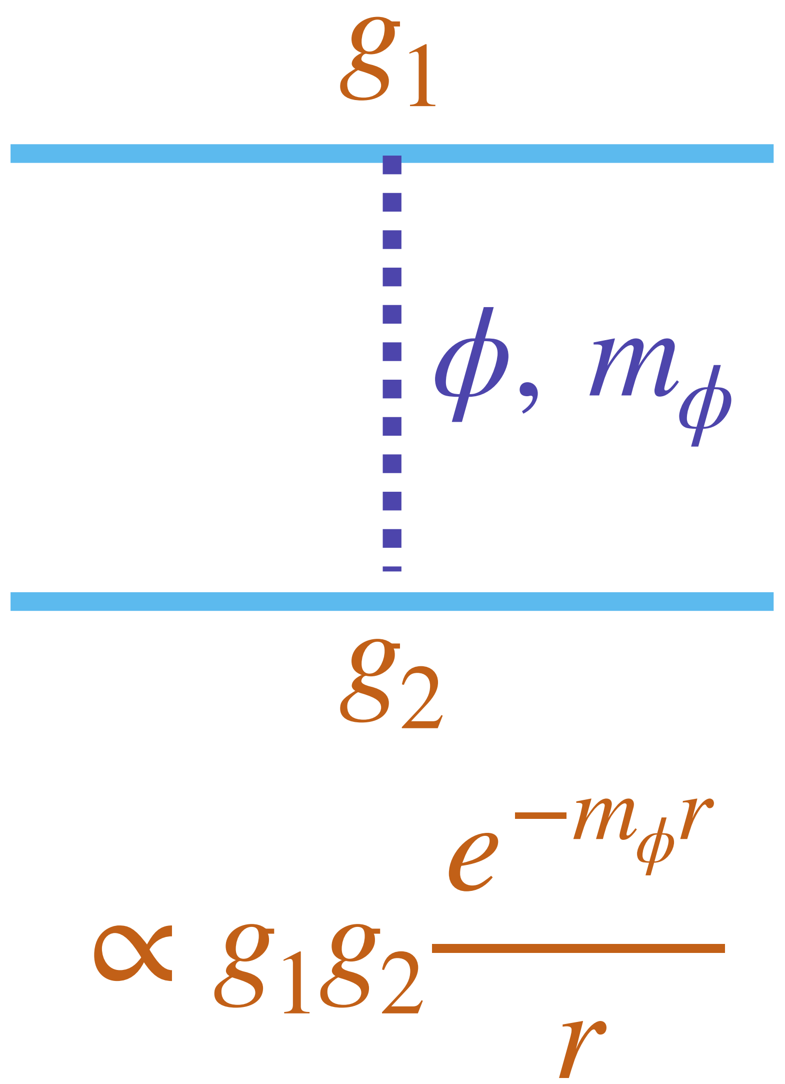

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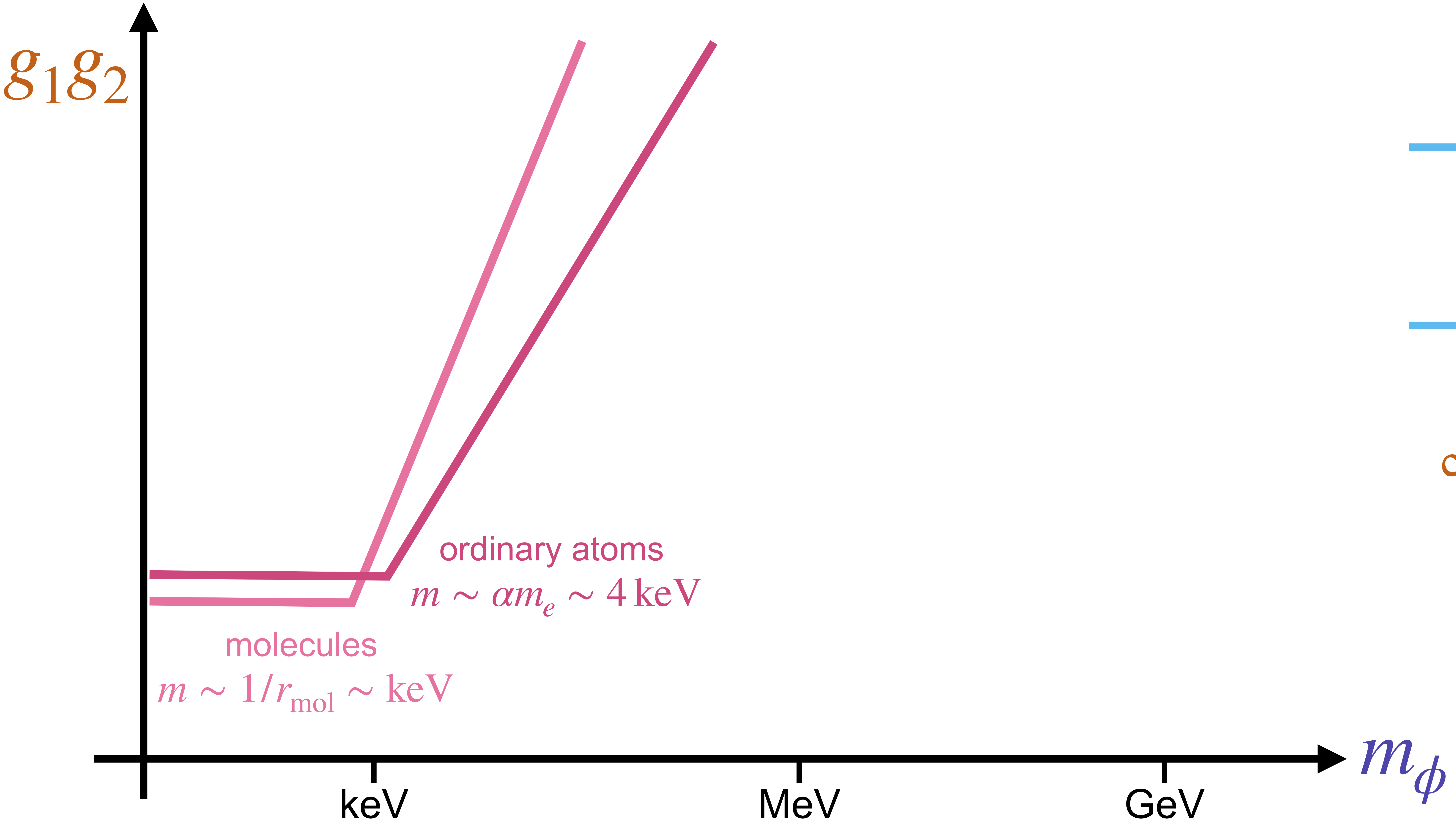

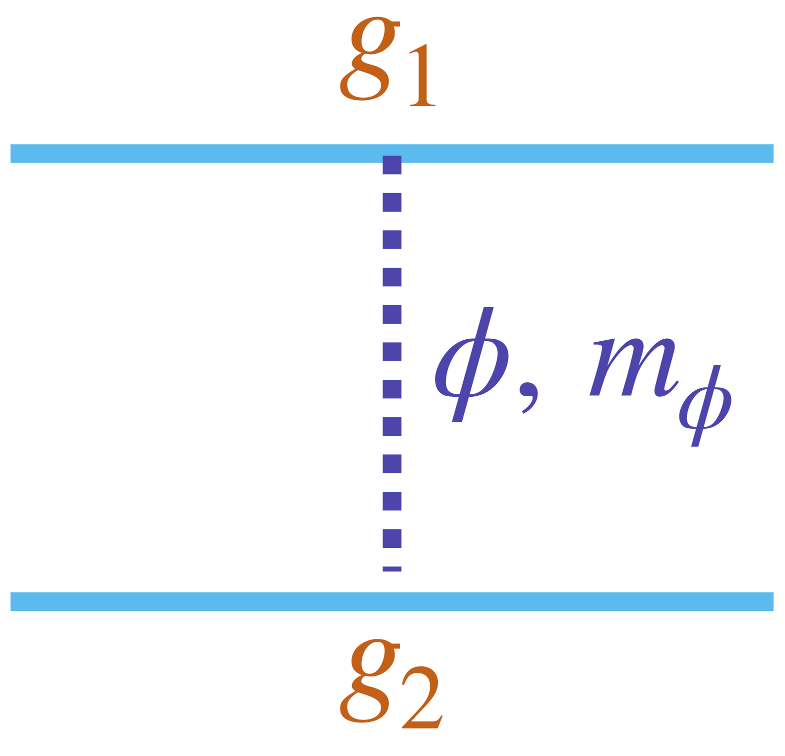

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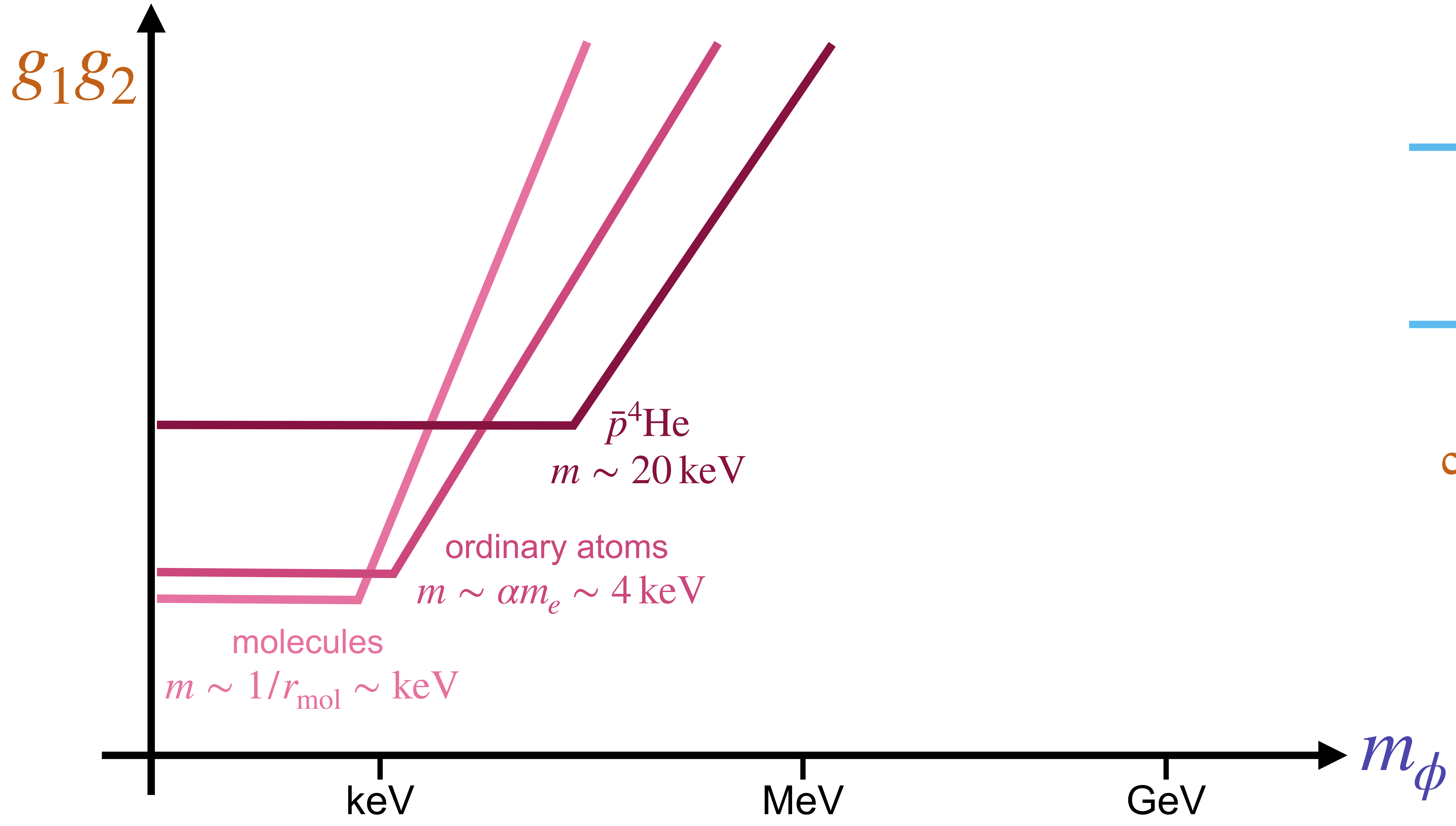

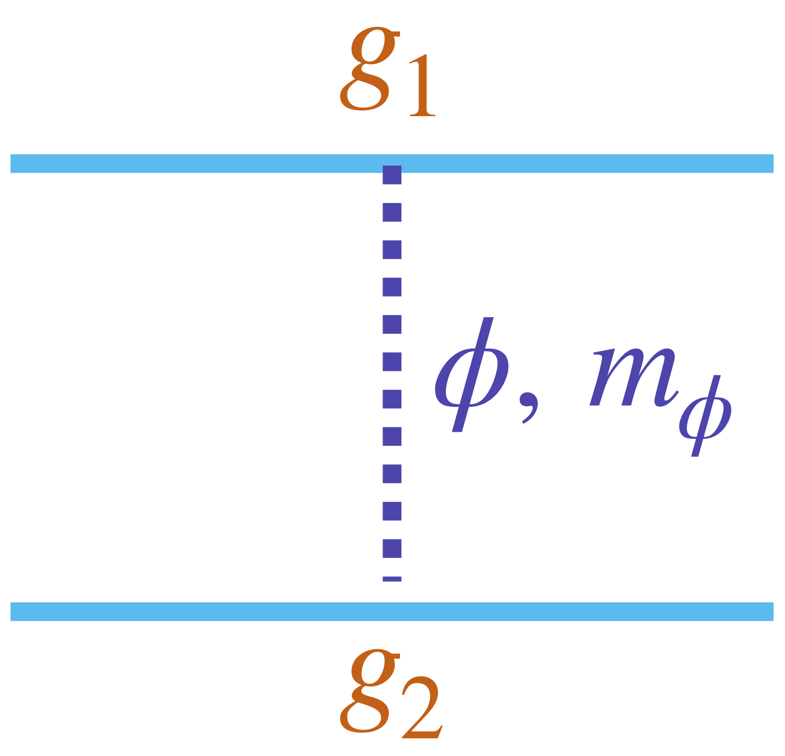

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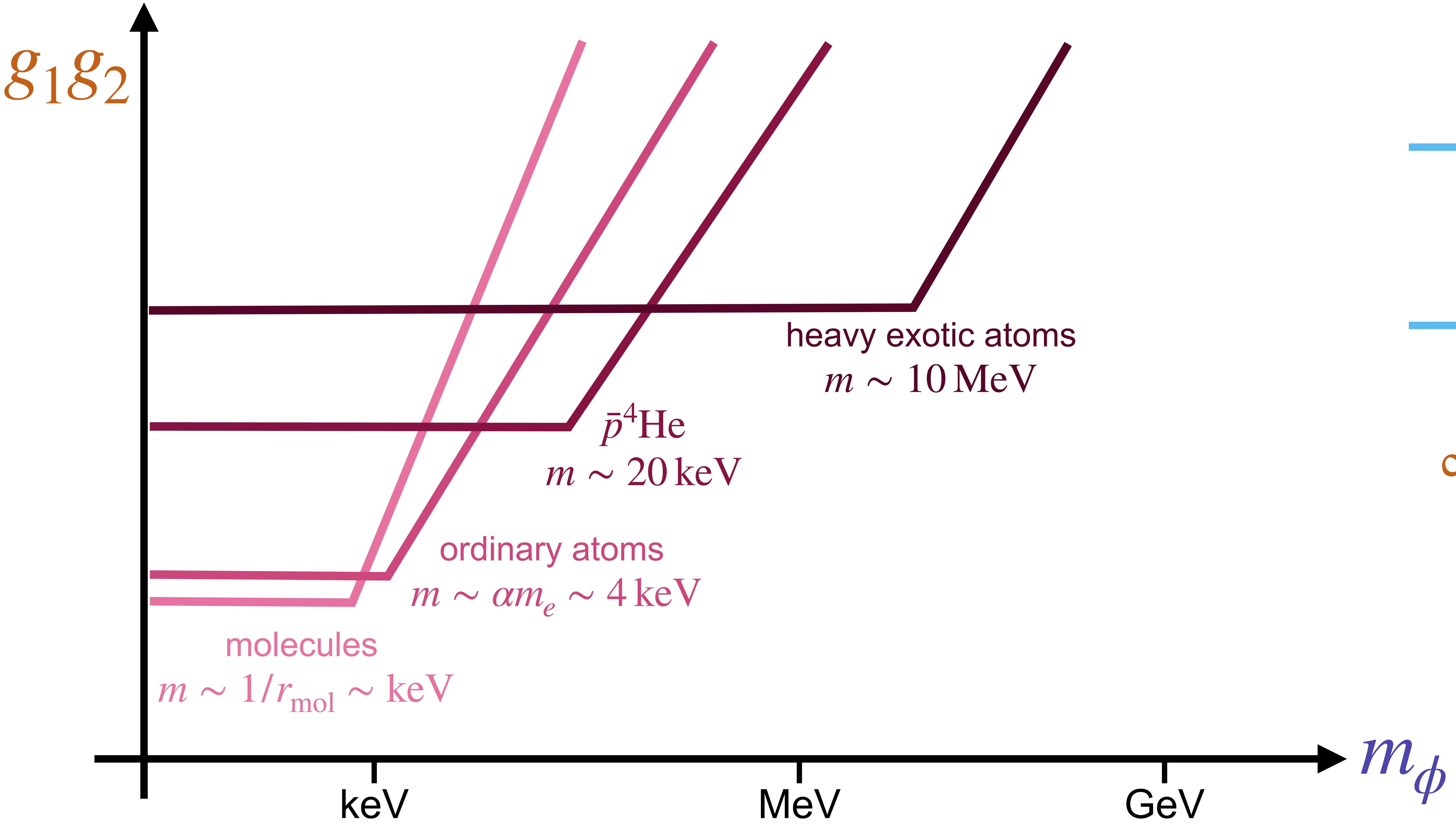

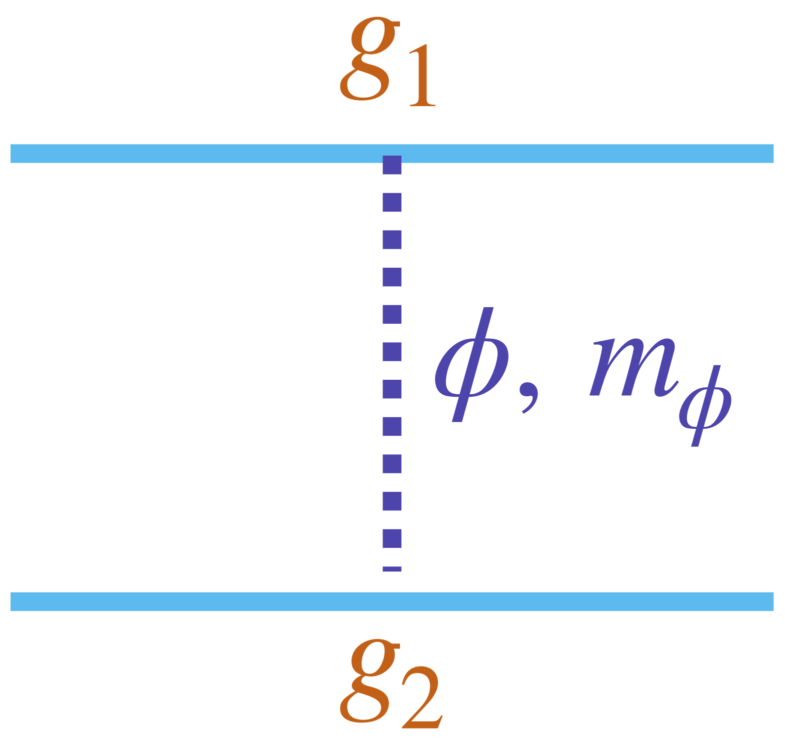

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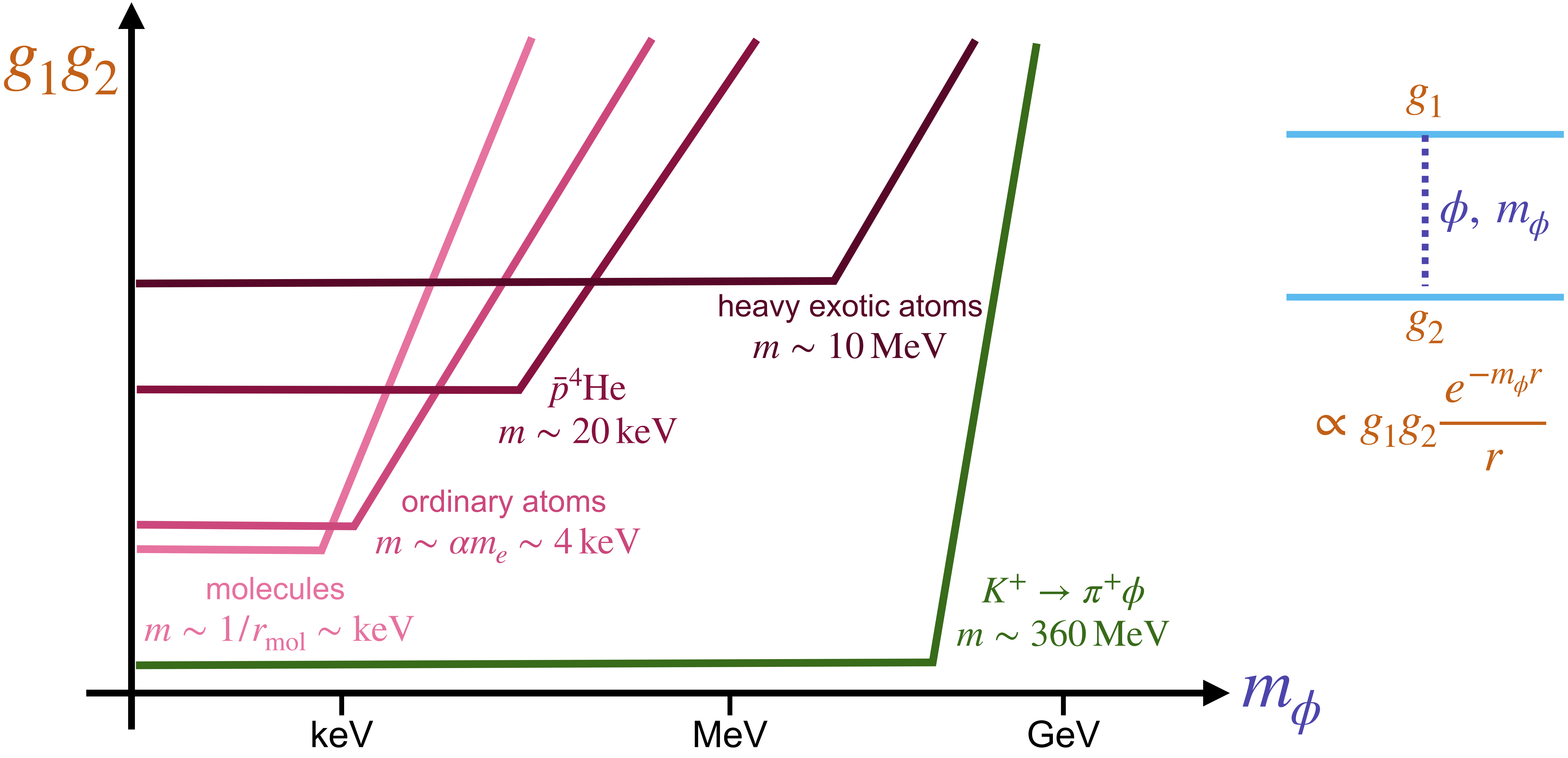
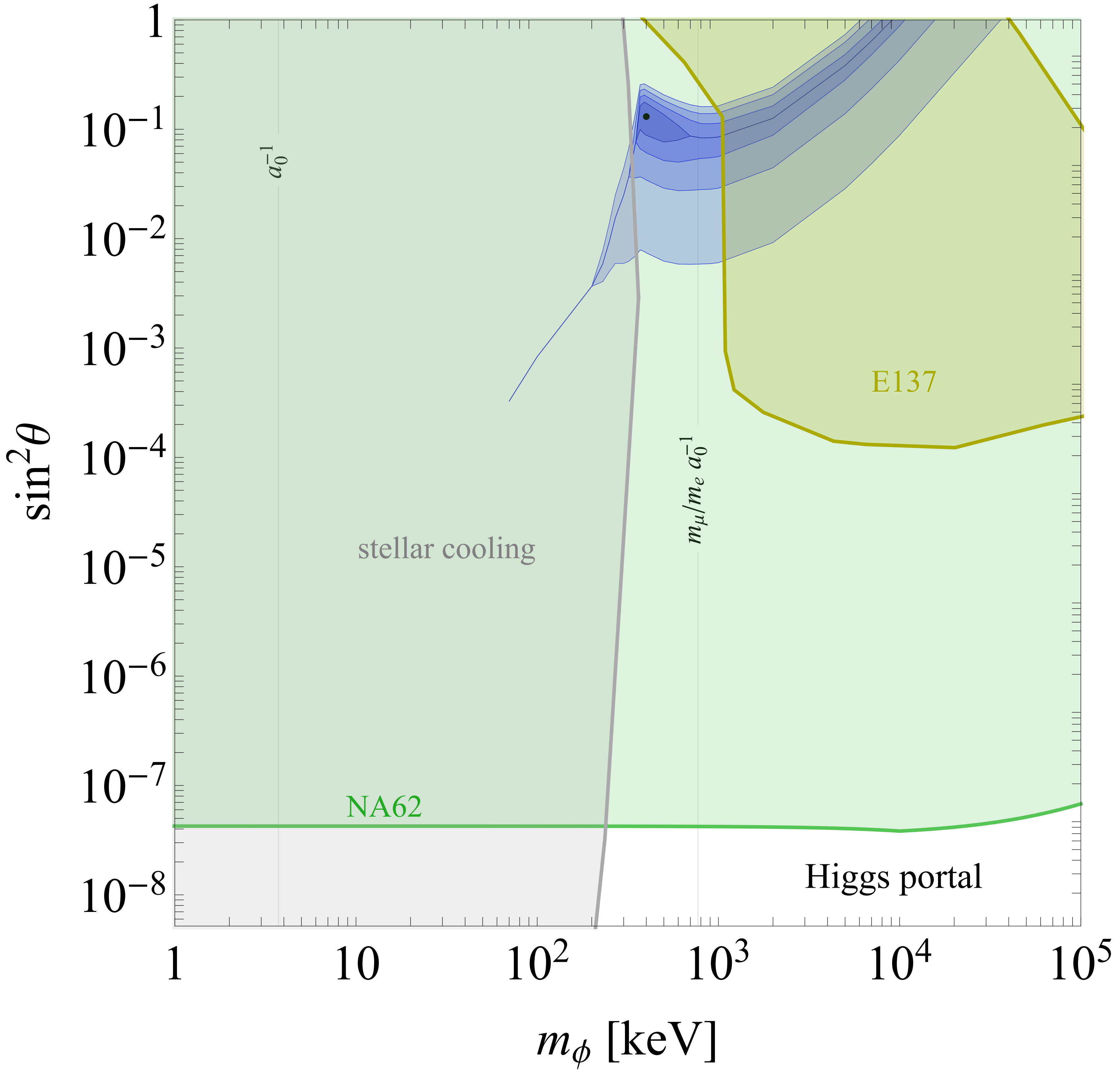


2022 Spectroscopy data

Higgs ϕ mixing



Delaunay, Karr, Kitahara, Koelemeij, YS, Zupan, PRL 23

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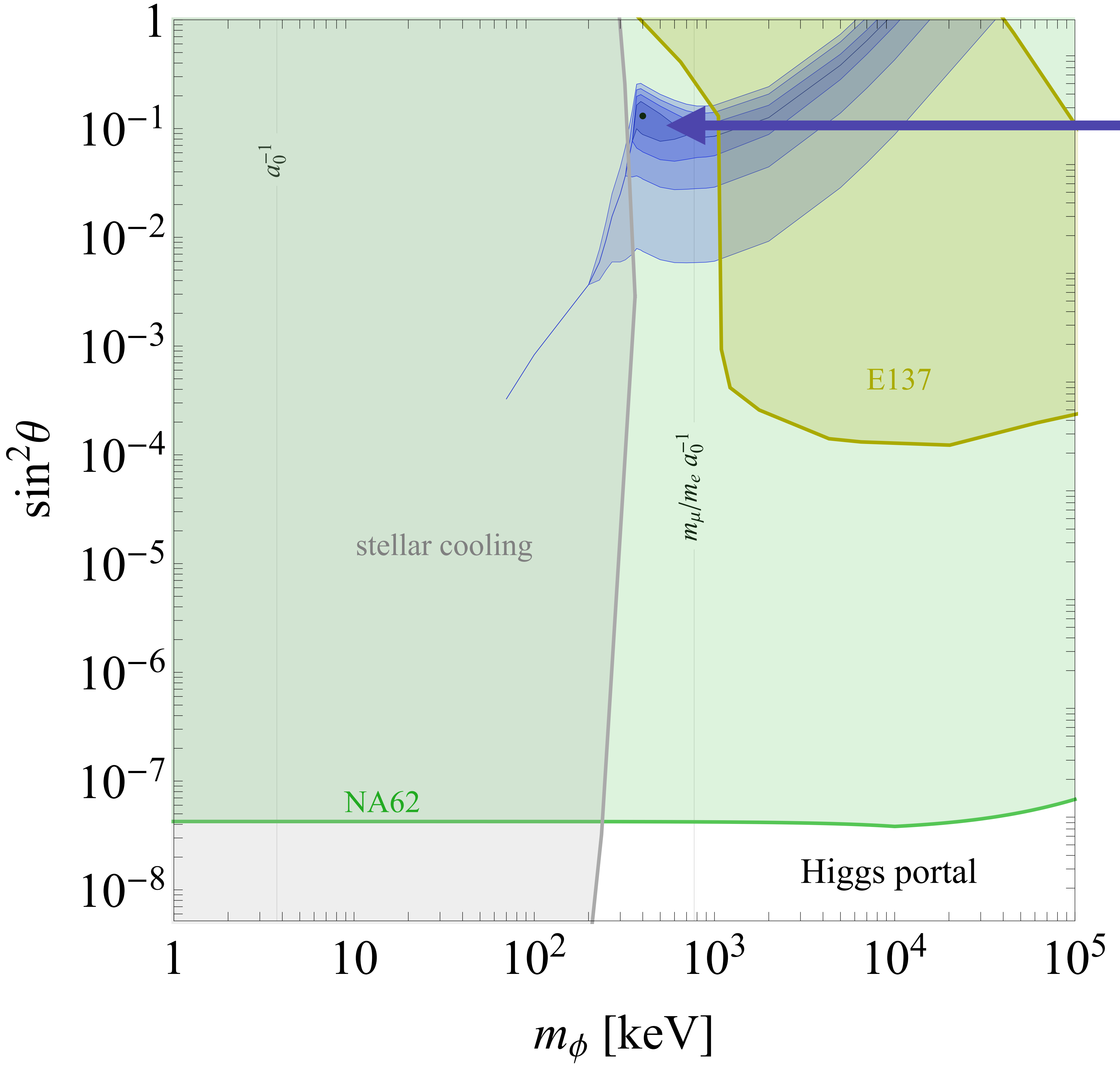

excess in spectroscopy data

Delaunay, Karr, Kitahara, Koelemeij, YS, Zupan, PRL 23

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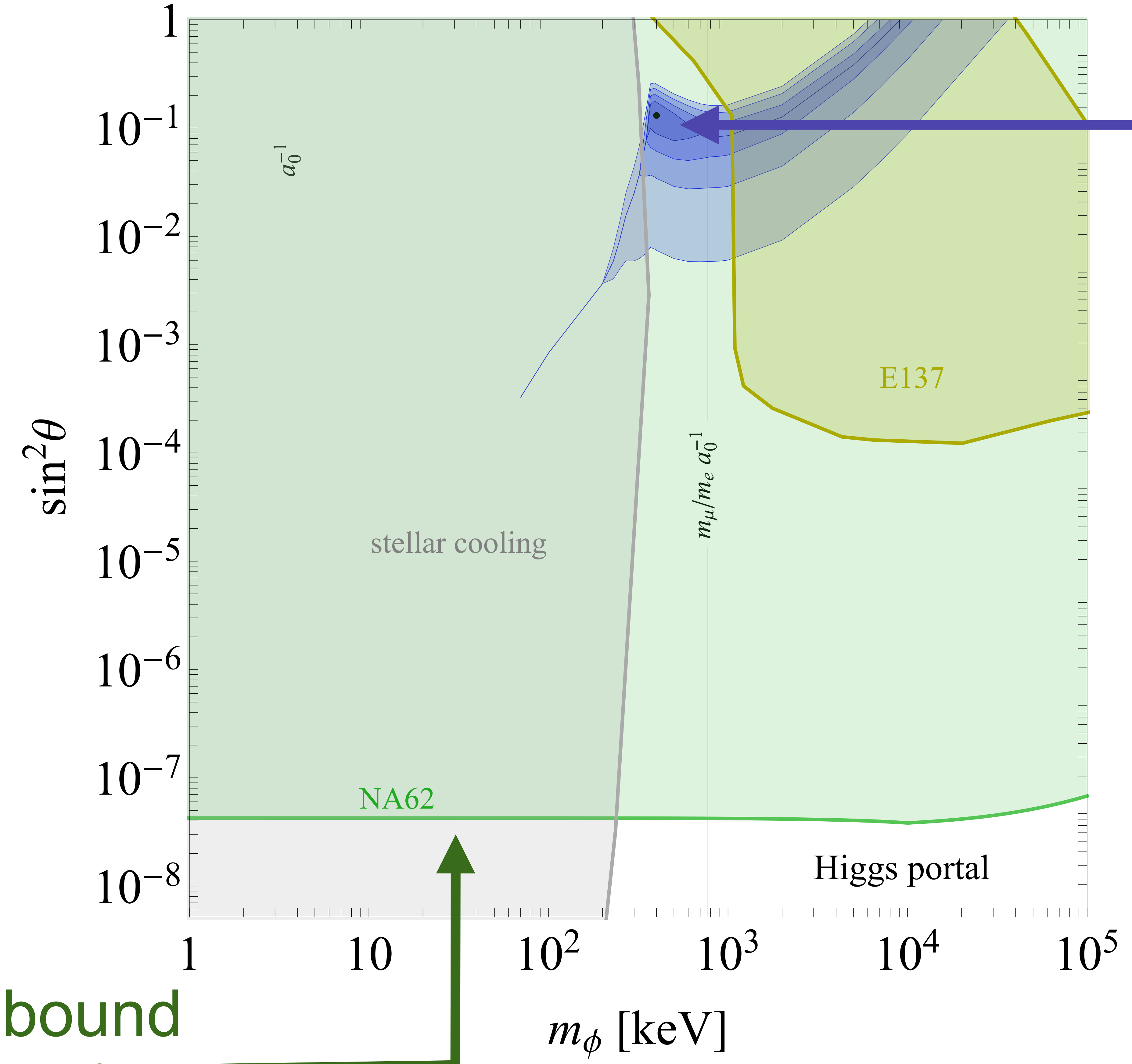

excess in
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very strong bound
from $K^+ \to \pi^+\phi$

Delaunay, Karr, Kitahara, Koelemeij, YS, Zupan, PRL 23

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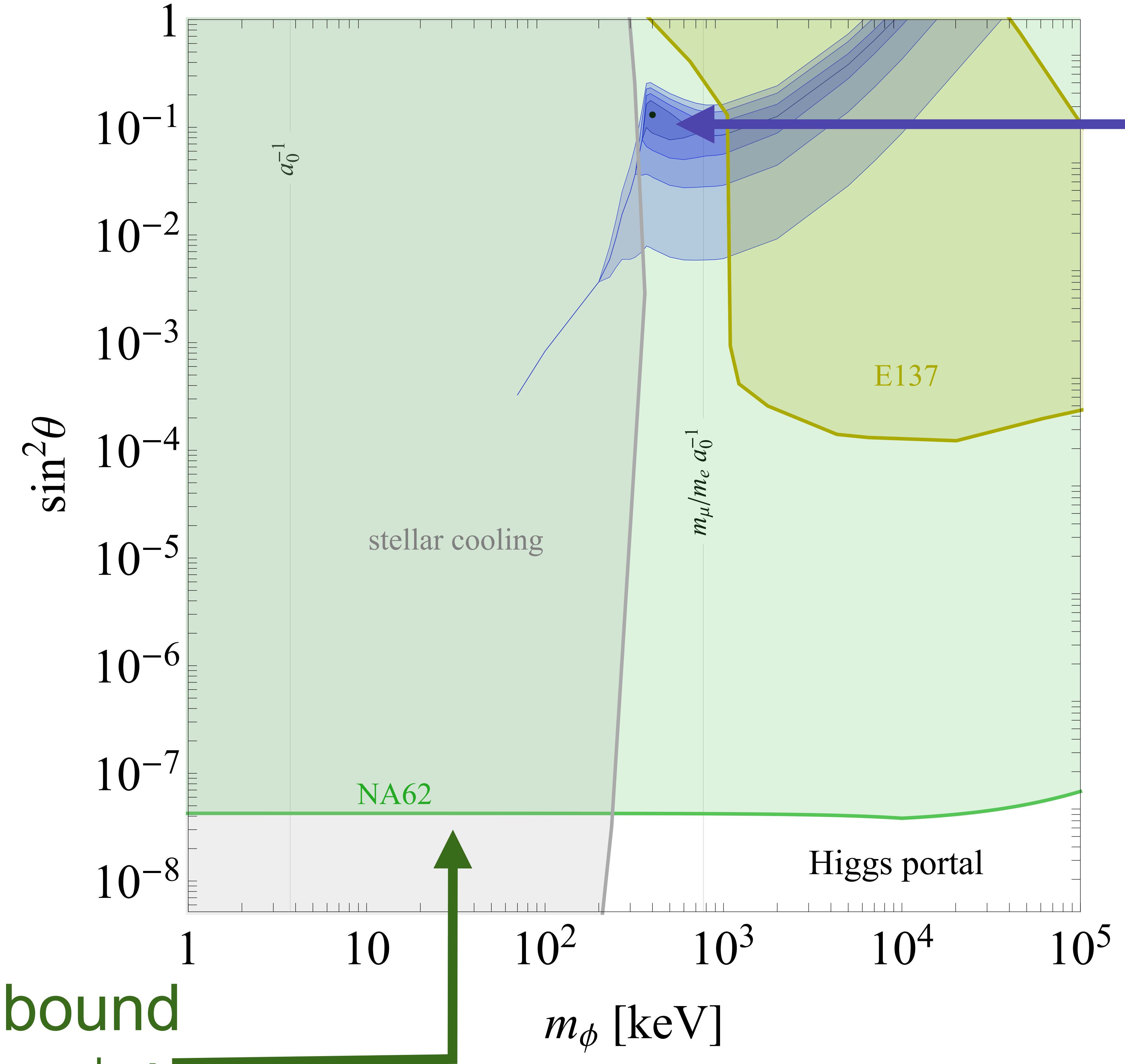

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very strong bound from $K^+ \to \pi^+\phi$

1. How robust is the Kaon bound? i.e. how to avoid it?

Delaunay, Karr, Kitahara, Koelemeij, YS, Zupan, PRL 23

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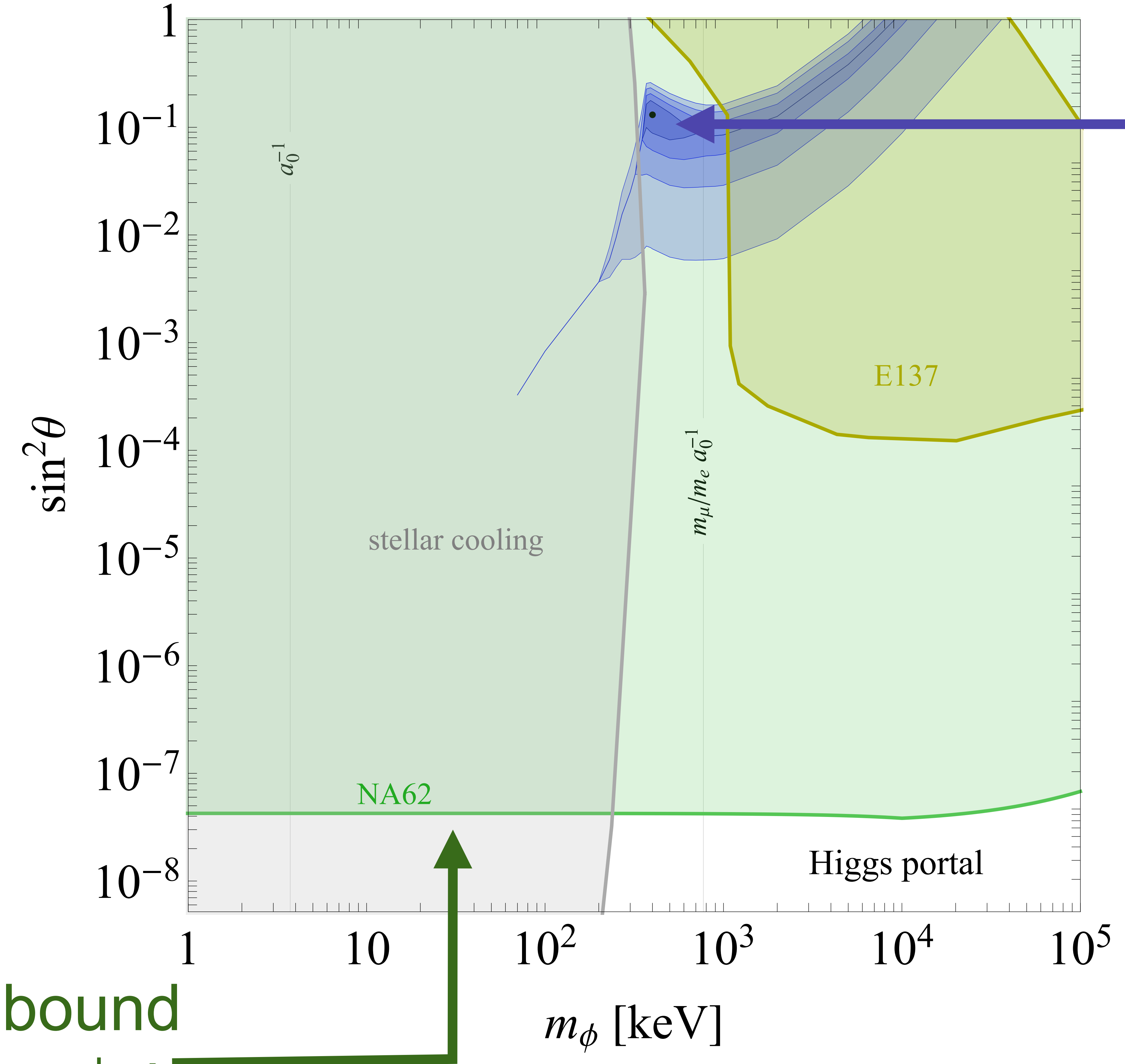

excess in spectroscopy data

very strong bound from $K^+ \to \pi^+\phi$

1. How robust is the Kaon bound?
   i.e. how to avoid it?
2. How can we go beyond it ?

Delaunay, Karr, Kitahara, Koelemeij, YS, Zupan, PRL 23

Can we avoid Kaon decay bounds?

	$K \to \pi\phi$	spectroscopy (nucleon coupling)
Higgs mixing		
uds: $\kappa_{u,d,s} = 1$		

$$\mathscr{L}^{\phi}_{\text{int}} \supset \frac{\phi}{f}\left(\frac{9\alpha_s}{8\pi}K_{\Theta}G^{a}_{\mu\nu}G^{a\mu\nu} - 2\kappa_W \mathscr{L}^{\Delta S=1}_{4q} + \kappa_{sd} m_s \bar{d}_L s_R + \kappa_{ds} m_d \bar{d}_R s_L - \sum_{\phi} \kappa_{\psi} m_{\psi} \bar{\psi}\psi\right)$$

Delaunay, Kitahara, YS, Zupan, 2501.16477

Can we avoid Kaon decay bounds?

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Delaunay, Kitahara, YS, Zupan, 2501.16477

Can we avoid Kaon decay bounds?

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	$1\Big[$	$\kappa_\Theta\Big)$
Higgs mixing		
uds: $\kappa_{u,d,s} = 1$	0	$\propto m_n^2$

only u, d, s couplings $\propto m_{u,d,s}$

$\Rightarrow$ avoid strong Kaon bounds

$\Rightarrow$ have spectroscopy signature

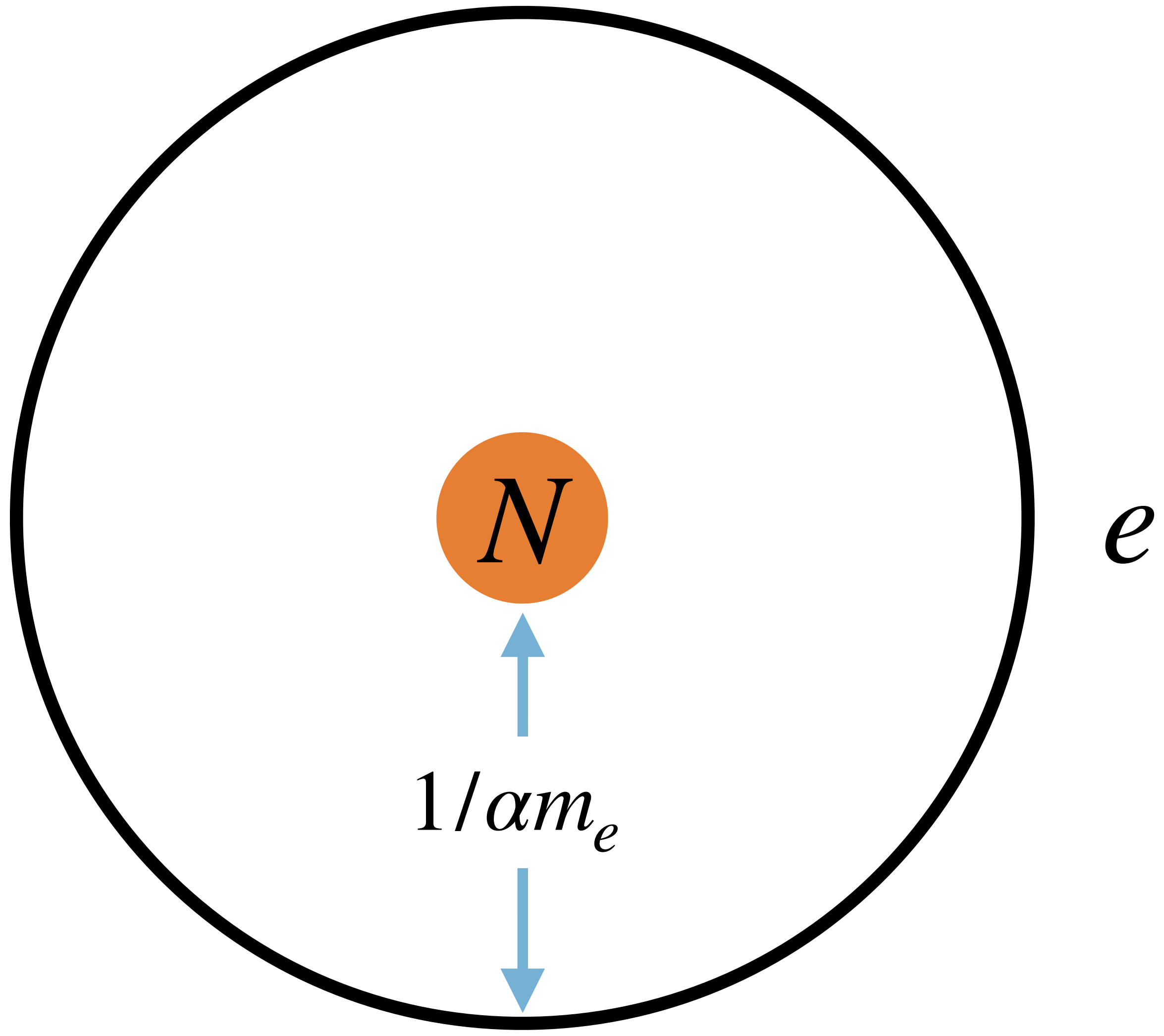
$$\mathscr{L}_{\text{int}}^{\phi} \supset \frac{\phi}{f}\left(\frac{9\alpha_s}{8\pi}K_\Theta G_{\mu\nu}^a G^{a\mu\nu} - 2\kappa_W \mathscr{L}_{4q}^{\Delta S=1} + \kappa_{sd} m_s \bar{d}_L s_R + \kappa_{ds} m_d \bar{d}_R s_L - \sum_{\phi} \kappa_\psi m_\psi \bar{\psi}\psi\right)$$

Delaunay, Kitahara, YS, Zupan, 2501.16477

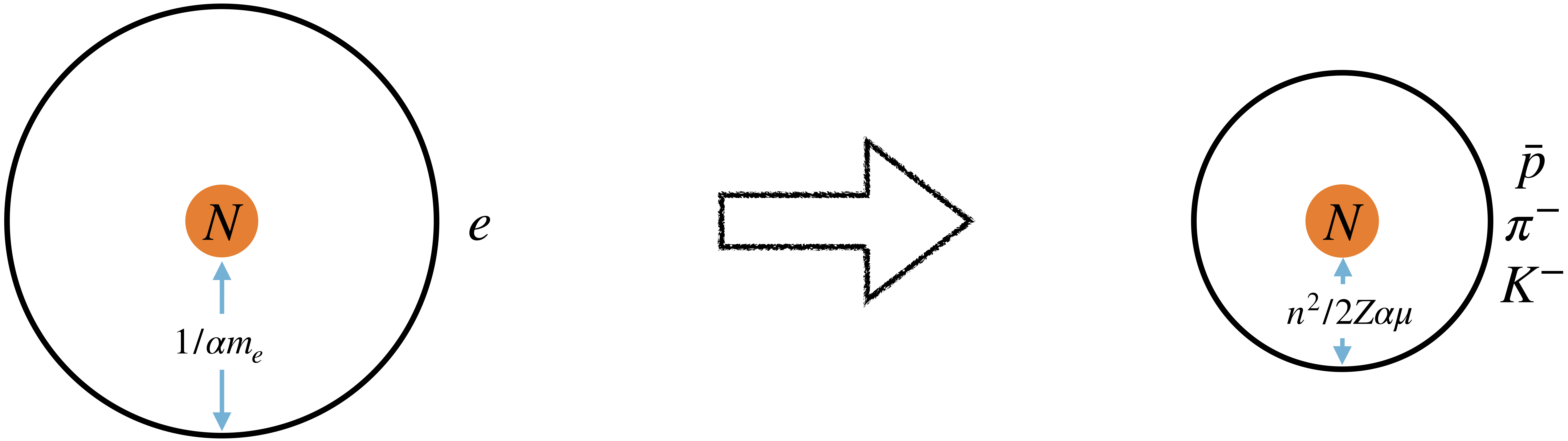
Probing new hadronic forces with heavy exotic atoms

Liu, Ohayon, Shtaif, YS, 2502.03537

Exotic atoms for BSM



Exotic atoms for BSM



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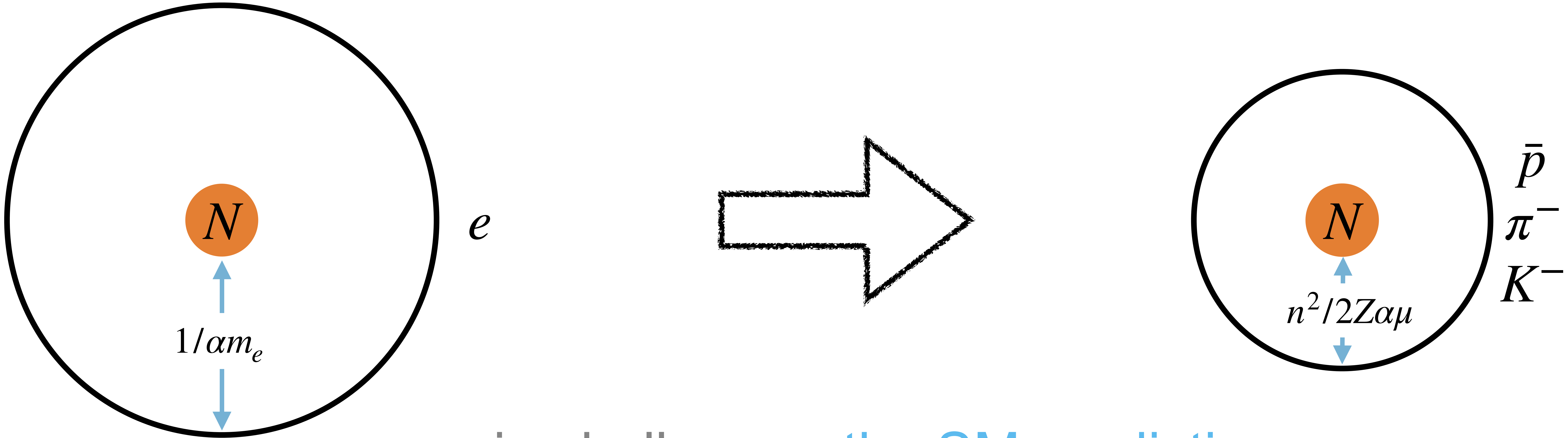
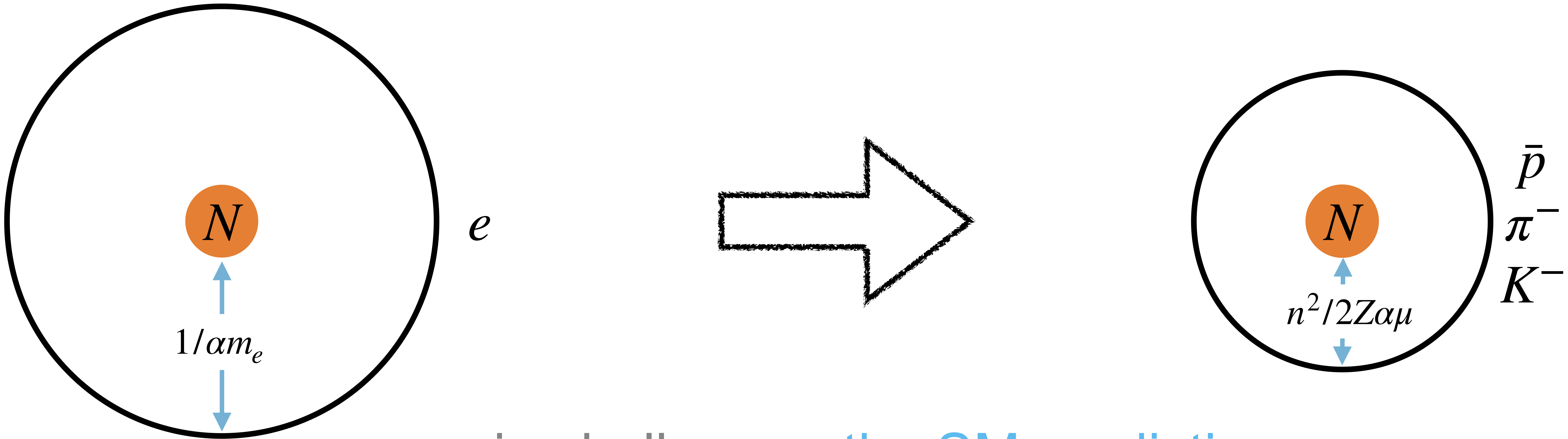


main challenge - the SM prediction

(hadronic interactions)

Exotic atoms for BSM



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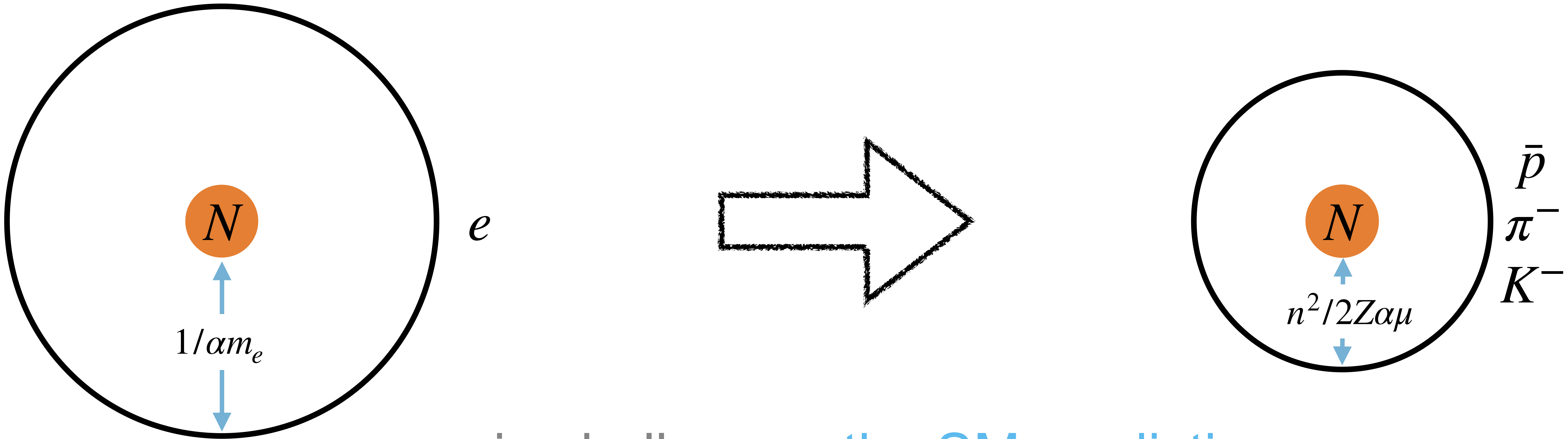
circular states $(n \gg 1,\ l = n-1)$ insensitive to local hadronic interactions
⇒ can be predicted (up to nuclear polarizability)

Paul et al PRL 21
Zatorski, Patkos, Pachucki PRA 22

Exotic atoms for BSM



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Paul et al PRL 21
Zatorski, Patkos, Pachucki PRA 22

new physics sensitivity

$g_N \times g_e\,,\, m_\phi \lesssim 4\,\mathrm{keV}$

$g_N \times g_H,\, m_\phi \lesssim 10\,\mathrm{MeV}$

Exotic atoms for BSM

$$E_n^{\rm th} = \overbrace{E_n^{\rm SM-NPol} + E_n^{\rm NPol}}^{E_n^{\rm SM}} + E_n^X$$

Liu, Ohayon, Shtaif, YS, 2502.03537

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Liu, Ohayon, Shtaif, YS, 2502.03537

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$\mathcal{O}(10^{-5})$

$\propto \alpha_E^{\mathrm{tot}} \left\langle r^{-4} \right\rangle$

can be extracted from data
by using 2 transitions (2T)

Liu, Ohayon, Shtaif, YS, 2502.03537

Exotic atoms for BSM

$$E_n^{\mathrm{th}} = \overbrace{E_n^{\mathrm{SM-NPol}} + E_n^{\mathrm{NPol}}}^{E_n^{\mathrm{SM}}} + E_n^X \longleftarrow \text{new physics } \frac{g_N^X g_H^X}{4\pi}\frac{e^{-m_X r}}{r}$$

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$\mathcal{O}(<10^{-6})$

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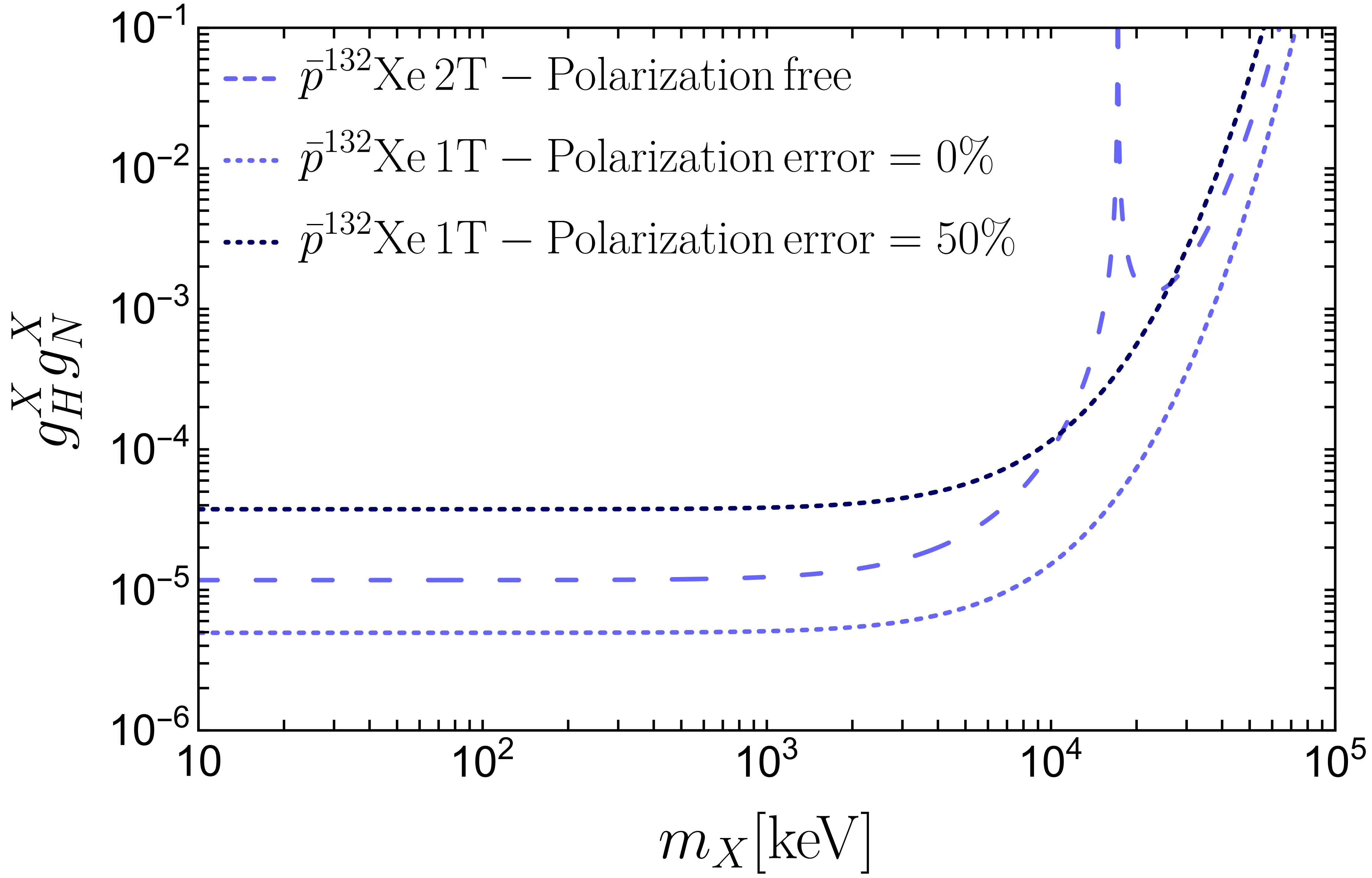
the nuclear polarizability effect



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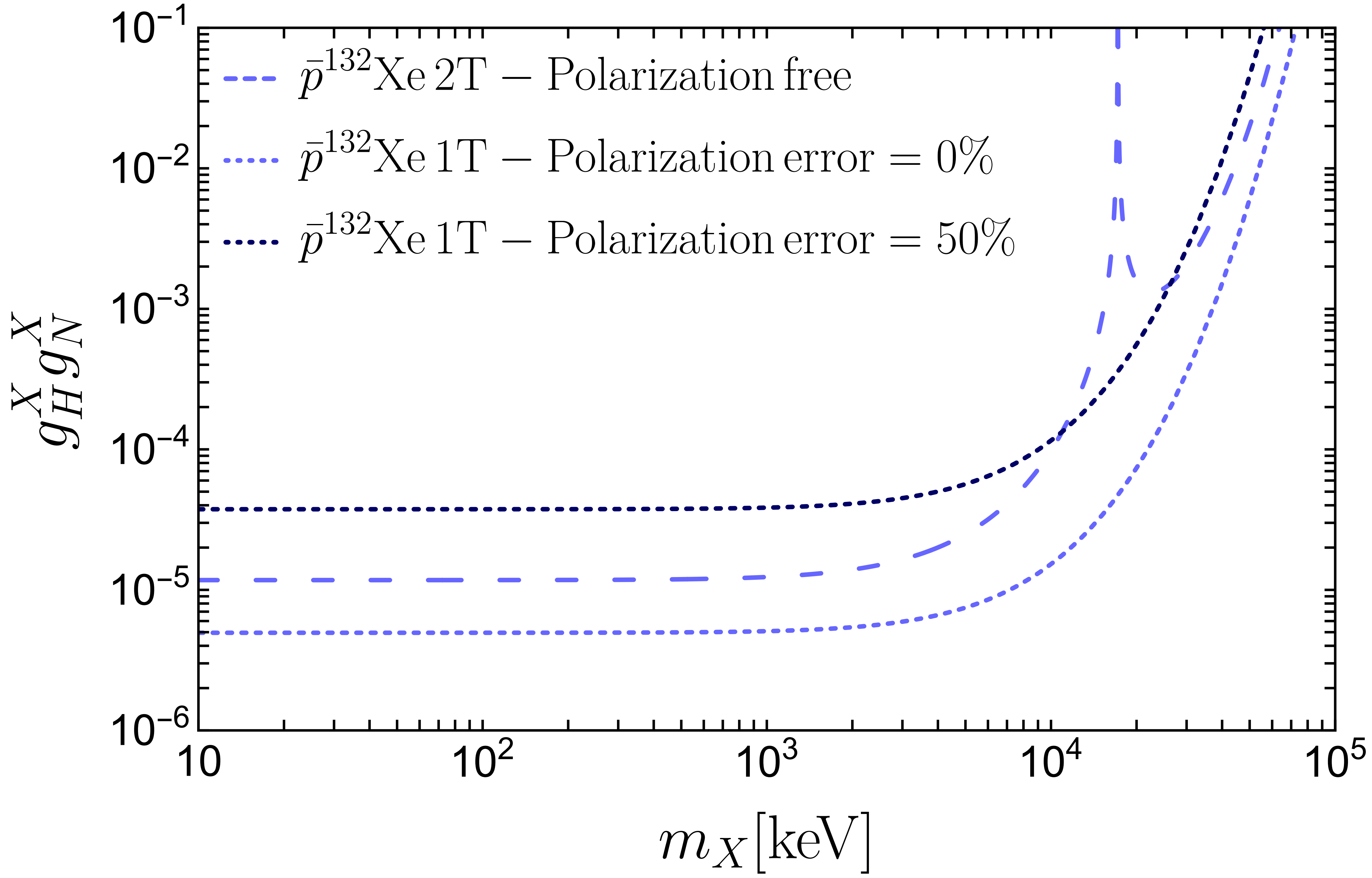
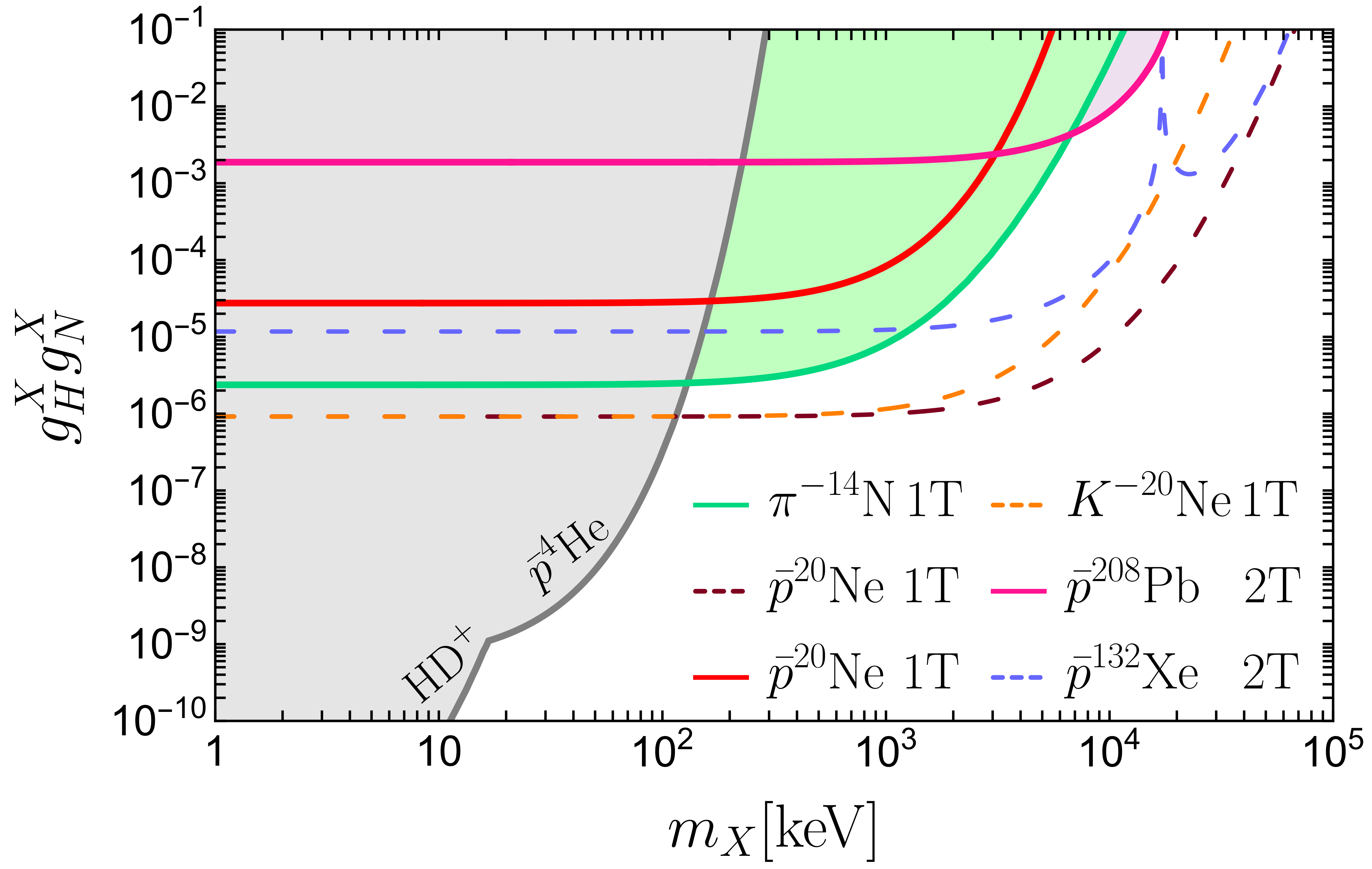


current and future bounds



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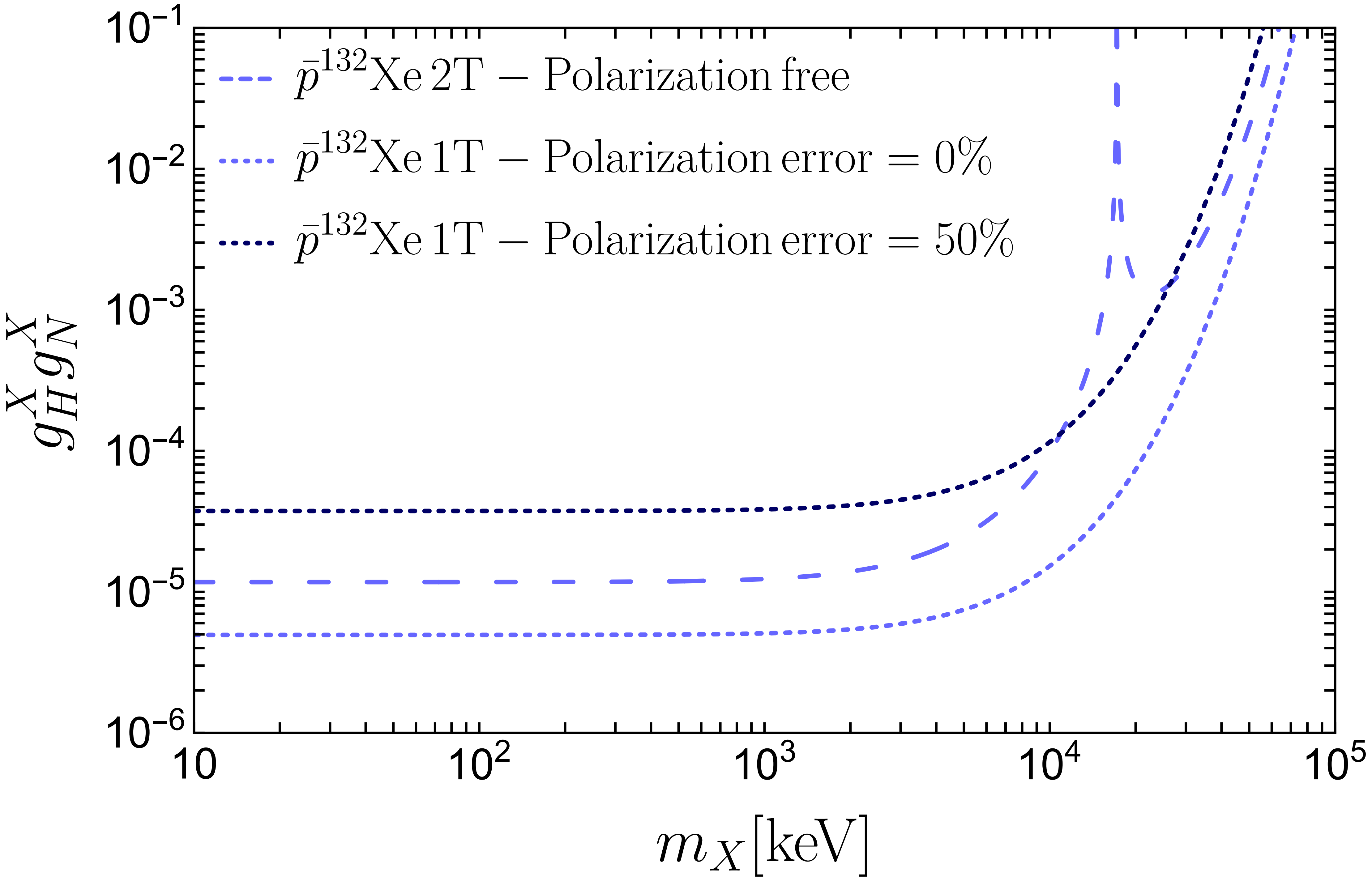

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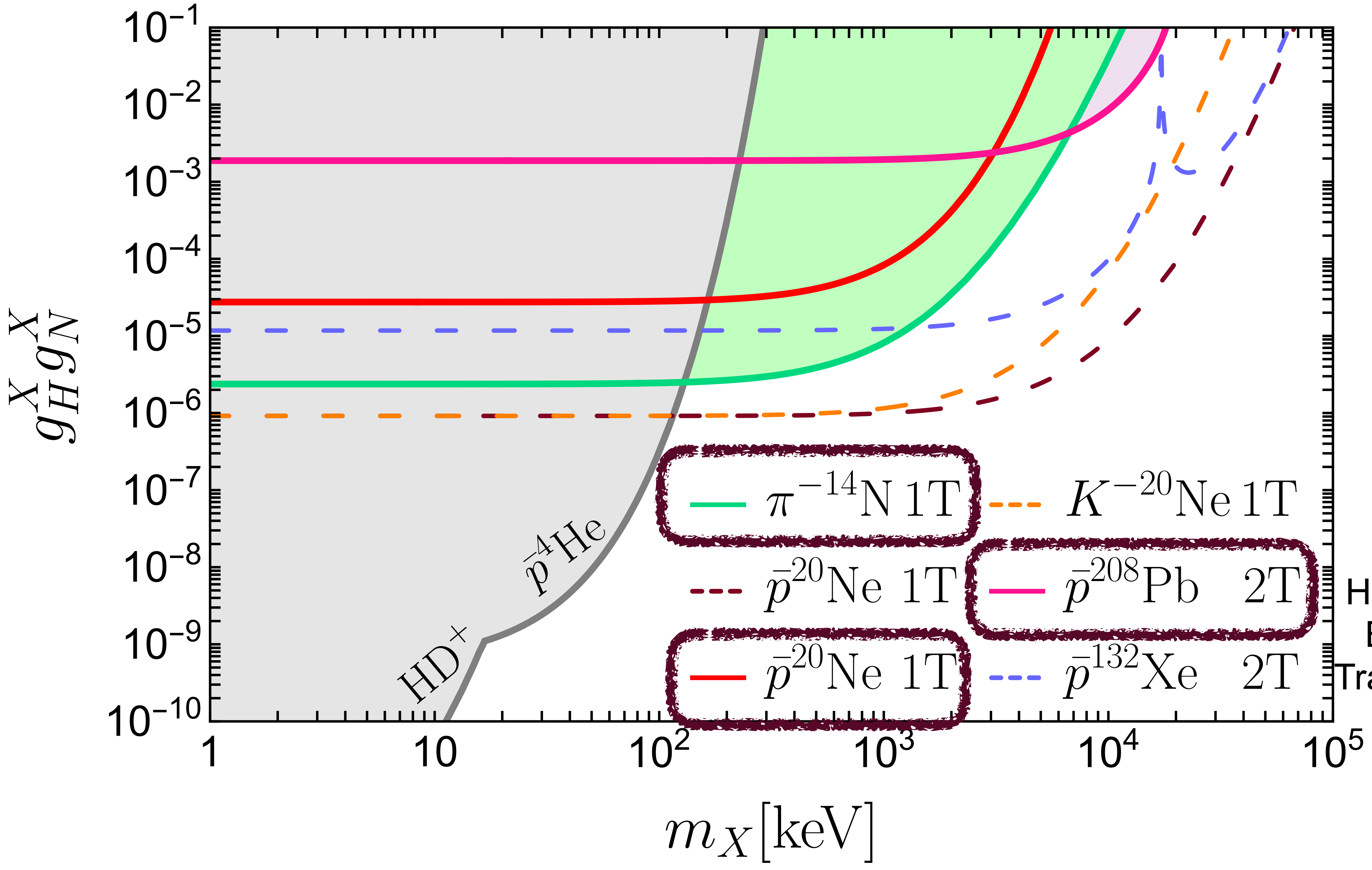


data

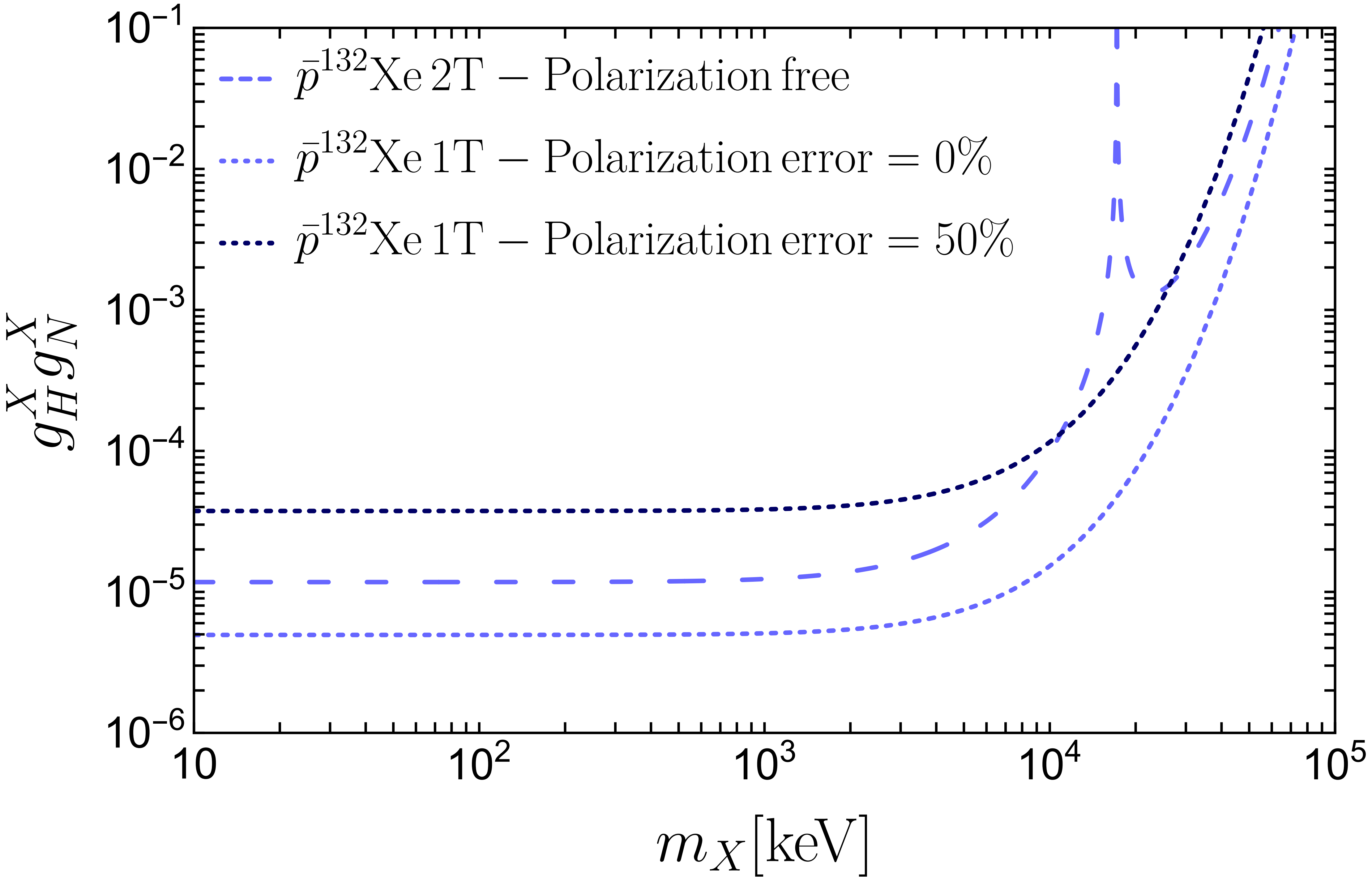
Hu et al NPA, 75
Borie, PRA 83
Trassinelli PLB 16

Liu, Ohayon, Shtaif, YS, 2502.03537

Exotic atoms for BSM

$$E_n^{\rm th} = \overbrace{E_n^{\rm SM-NPol} + E_n^{\rm NPol}}^{E_n^{\rm SM}} + E_n^X$$ ← new physics $\frac{g_N^X g_H^X}{4\pi}\frac{e^{-m_X r}}{r}$

the nuclear polarizability effect



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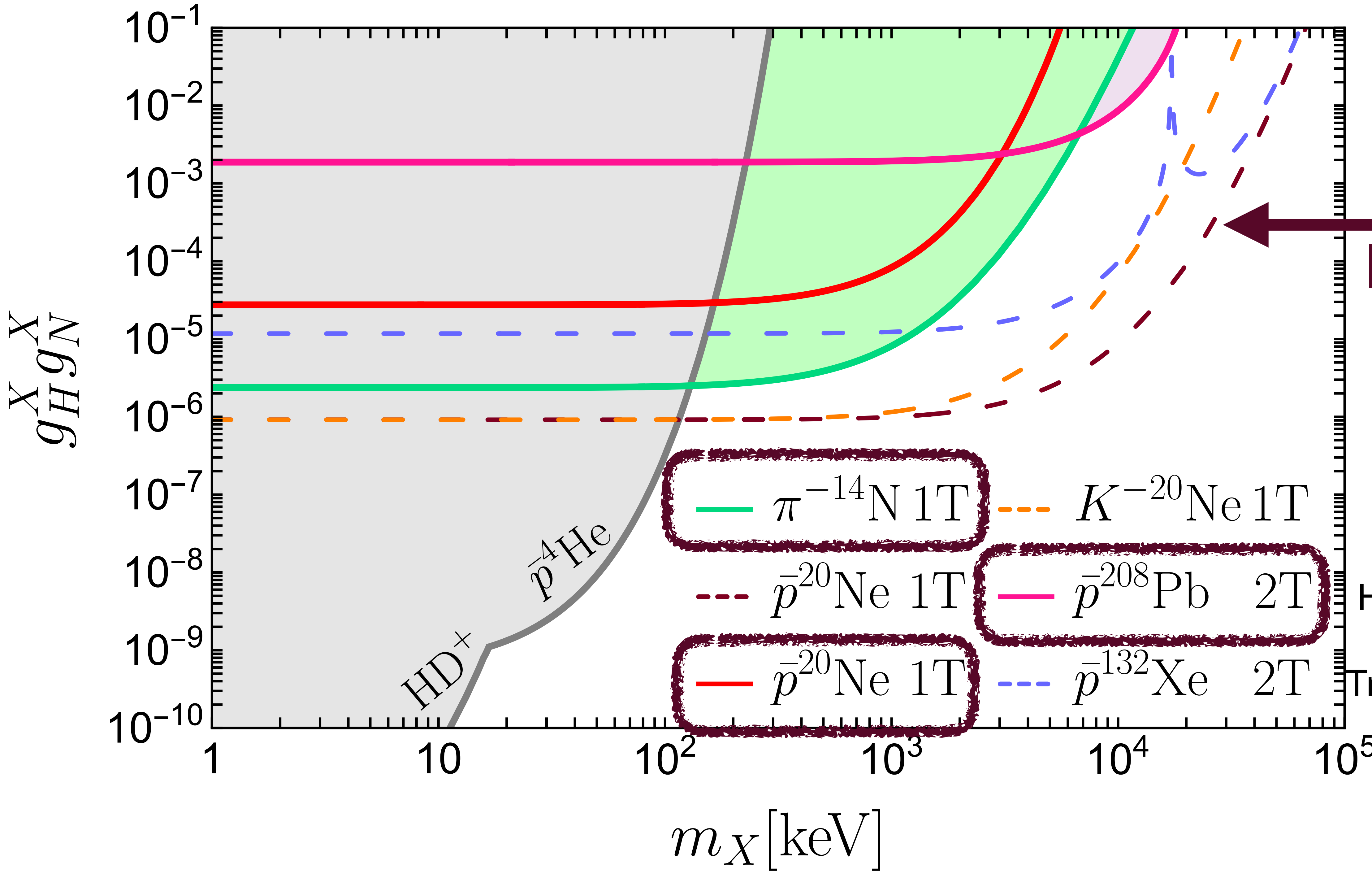

$\mathcal{O}(10^{-6})$
PAX goal

data

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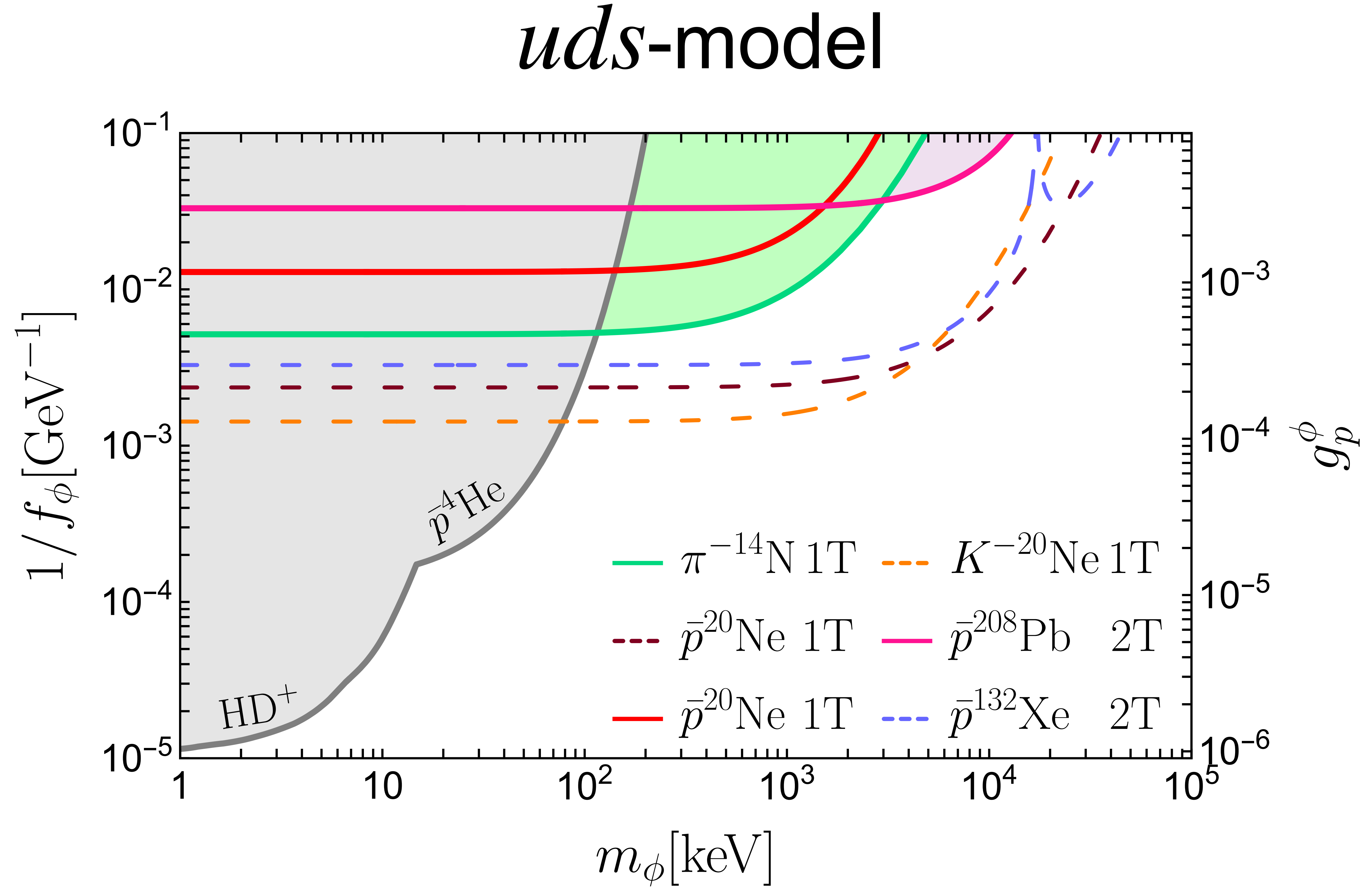
Exotic atoms for BSM

$$\frac{\phi}{f_\phi}\sum_{q=u,d,s} m_q\bar{q}q$$



no kaon bounds, but spectroscopy signature

Liu, Ohayon, Shtaif, YS, 2502.03537

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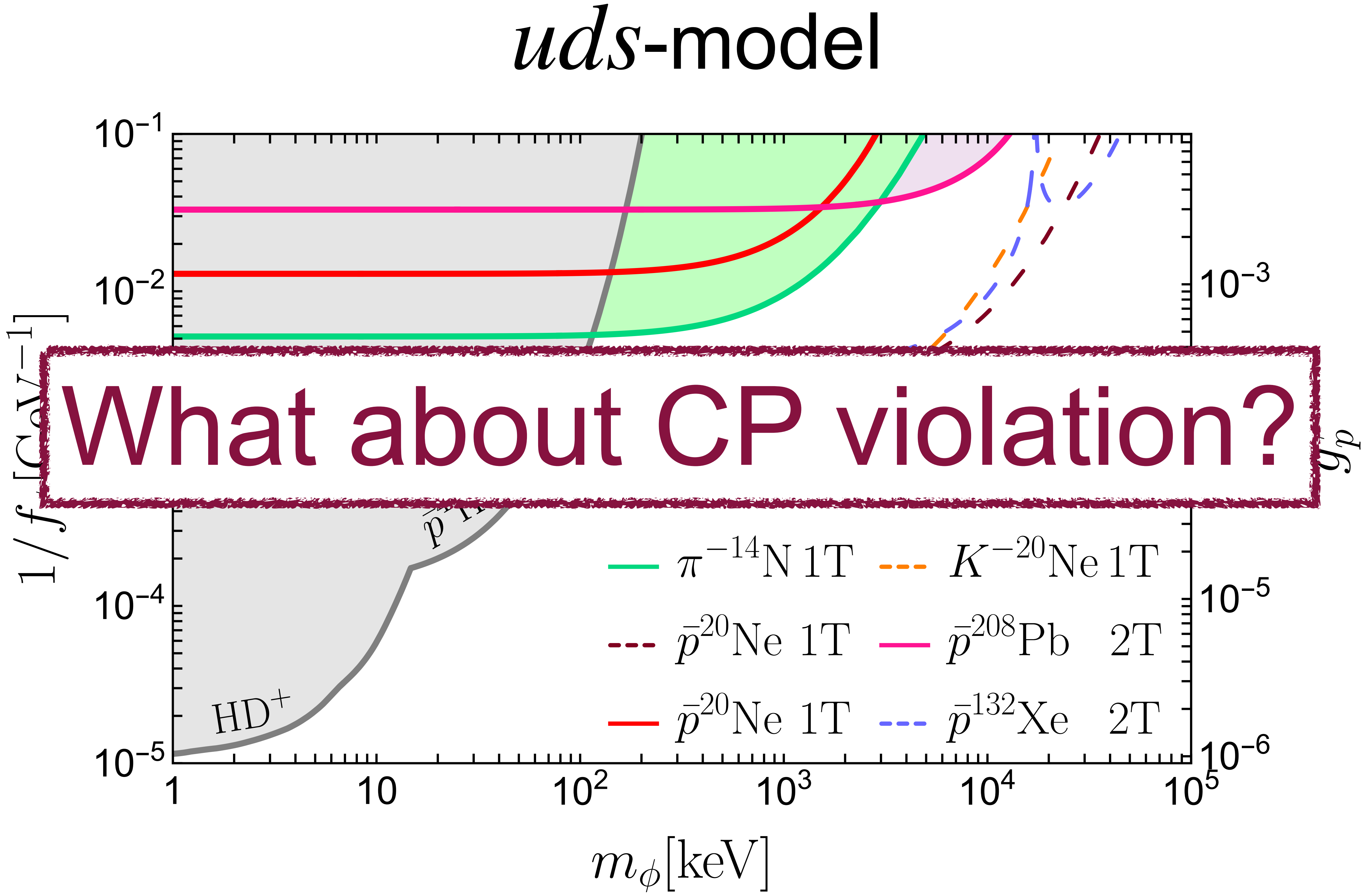

What about CP violation?

no kaon bounds, but spectroscopy signature

Liu, Ohayon, Shtaif, YS, 2502.03537

CP violation

$$\phi(g_{\mathrm{S}}^{\psi}\bar{\psi}\psi + i g_{\mathrm{P}}^{\psi}\bar{\psi}\gamma_5\psi)$$

CP violation

$$\phi(g_{\mathrm{S}}^{\psi}\bar{\psi}\psi + i g_{\mathrm{P}}^{\psi}\bar{\psi}\gamma_5\psi) \quad \Rightarrow \quad V_{\mathrm{SP}} \propto g_{\mathrm{S}}^{\psi_1} g_{\mathrm{P}}^{\psi_2} \frac{\vec{\sigma}^{\psi_1}\cdot\hat{r}}{2m_N}\left(\frac{1}{r} + m_\phi\right)\frac{e^{-m_\phi r}}{r}$$

CP violation

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electric dipole moment (EDM) ⇒ CP violation in low energy systems

CP violation

$$\phi(g_{\mathrm{S}}^{\psi}\bar{\psi}\psi + i g_{\mathrm{P}}^{\psi}\bar{\psi}\gamma_5\psi)$$

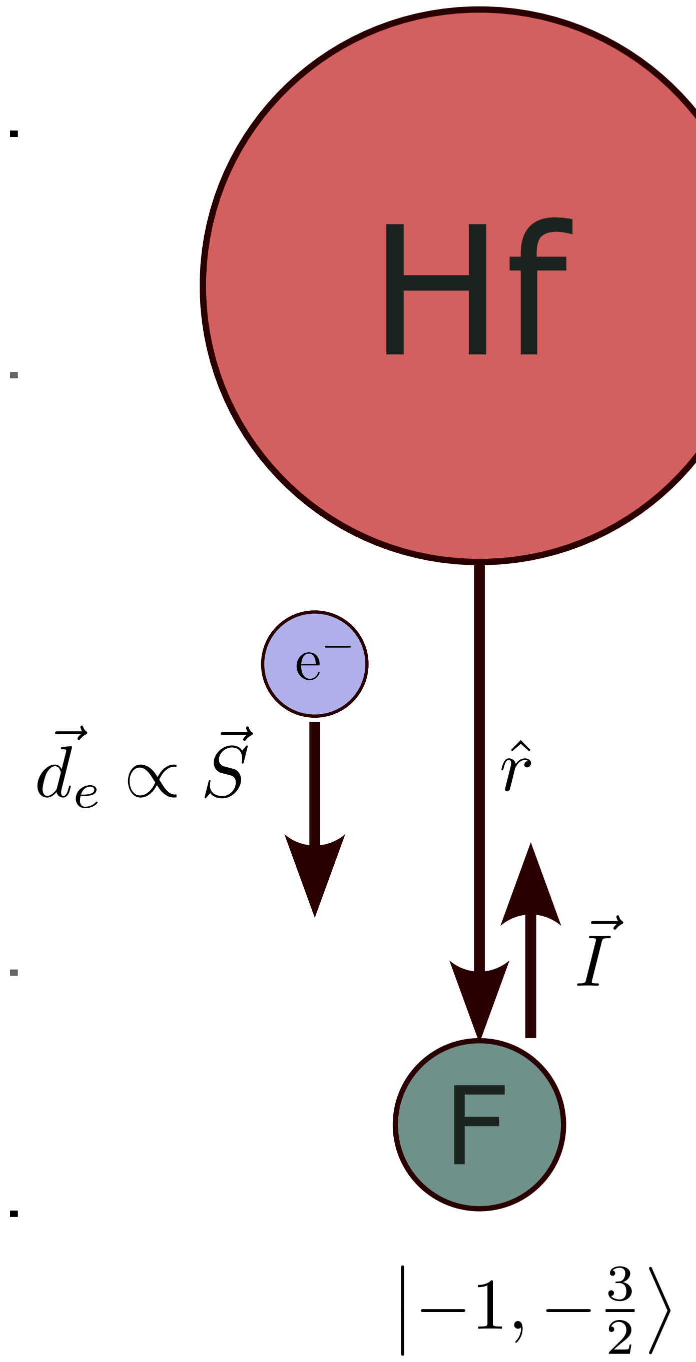
➡

$$V_{\mathrm{SP}} \propto g_{\mathrm{S}}^{\psi_1} g_{\mathrm{P}}^{\psi_2} \frac{\vec{\sigma}^{\psi_1}\cdot\hat{r}}{2m_N}\left(\frac{1}{r}+m_\phi\right)\frac{e^{-m_\phi r}}{r}$$

electric dipole moment (EDM) $\Rightarrow$ CP violation in low energy systems

What we can learn from the electron EDM about CPV
long range hadronic interactions?

CP violation in diatomic molecules

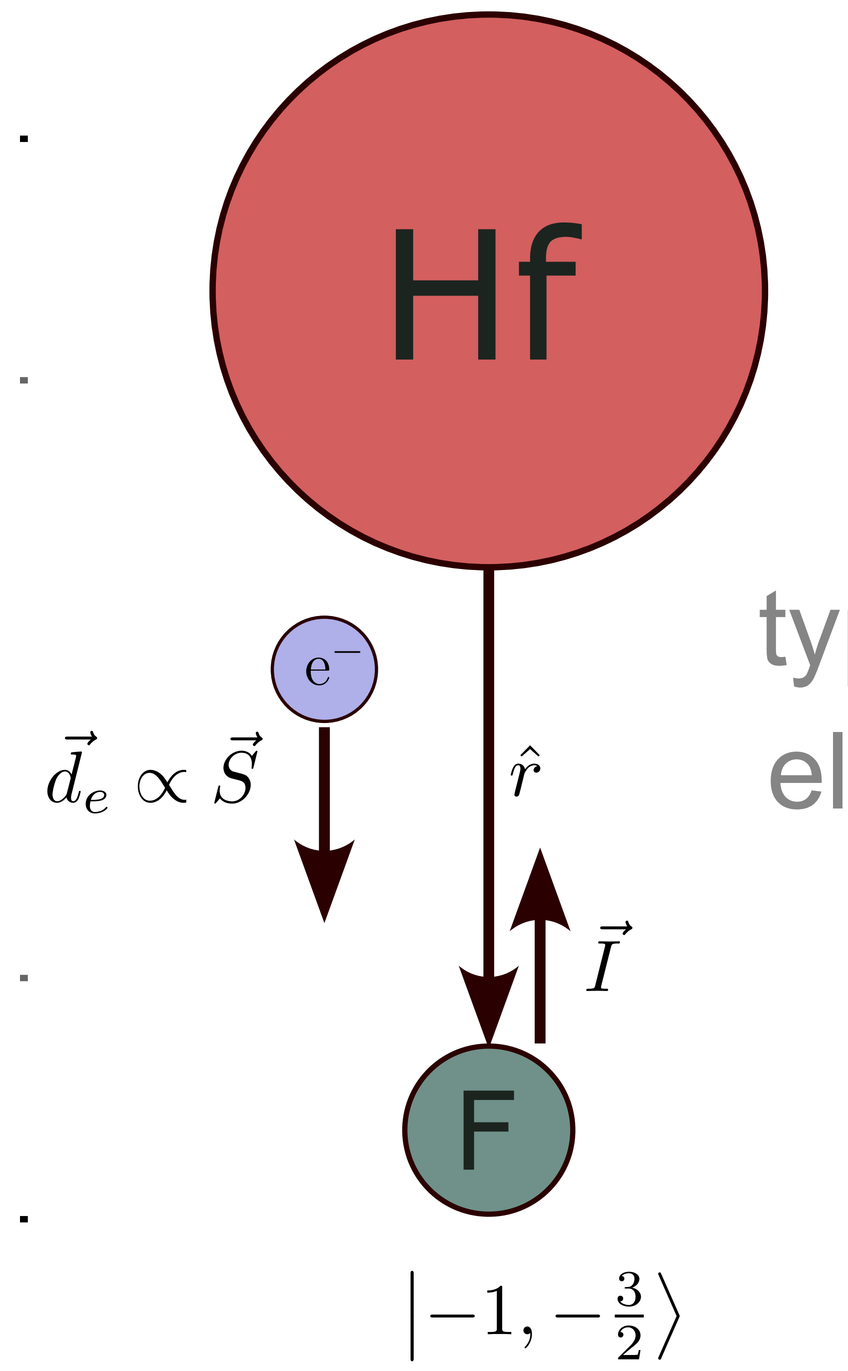


typical use for the electron electric dipole moment, d_e

Baruch, Changala, Shagam, YS, PRL 24

CP violation in diatomic molecules

$$E_{\Omega,m_F} = E_0 + E_S + E_Z + E_{CPV}$$



typical use for the electron electric dipole moment, d_e

$|\Omega, m_F\rangle$ - the quantum states
Ω - projection of electronic angular momentum on $\hat{r}$
m_F - projection of total angular momentum on $\hat{r}$

Baruch, Changala, Shagam, YS, PRL 24

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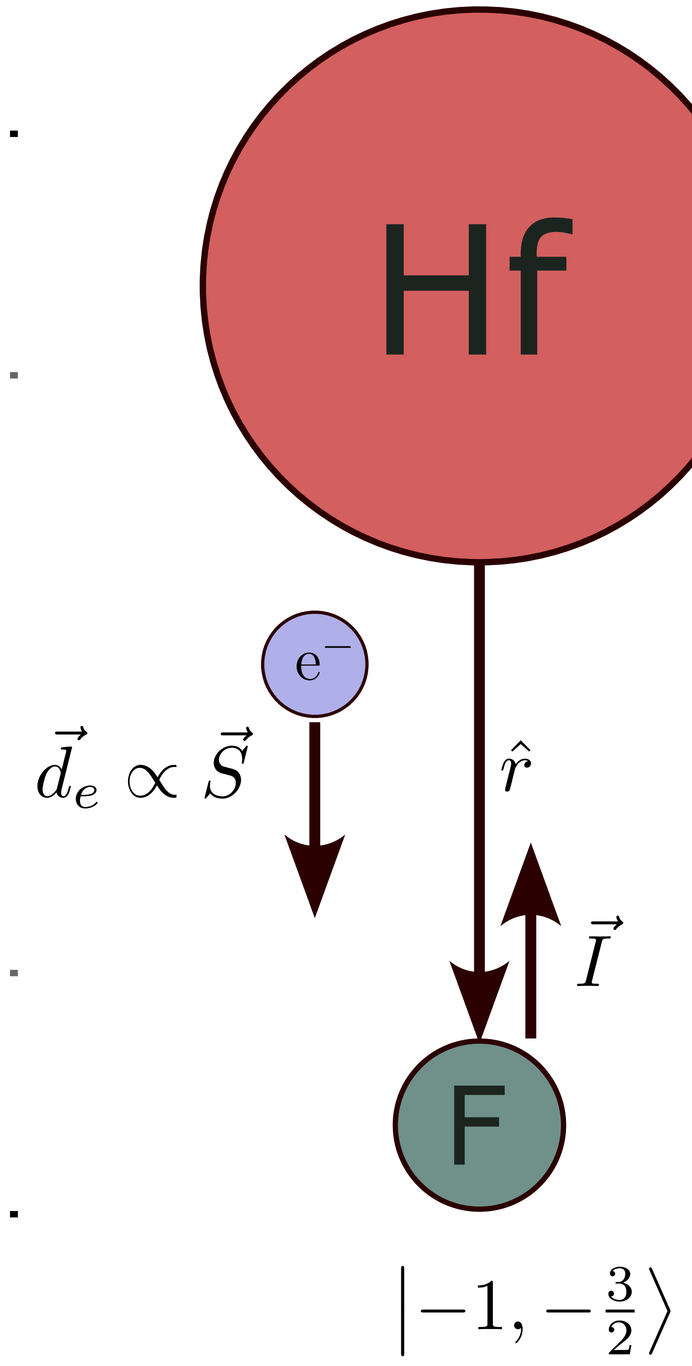

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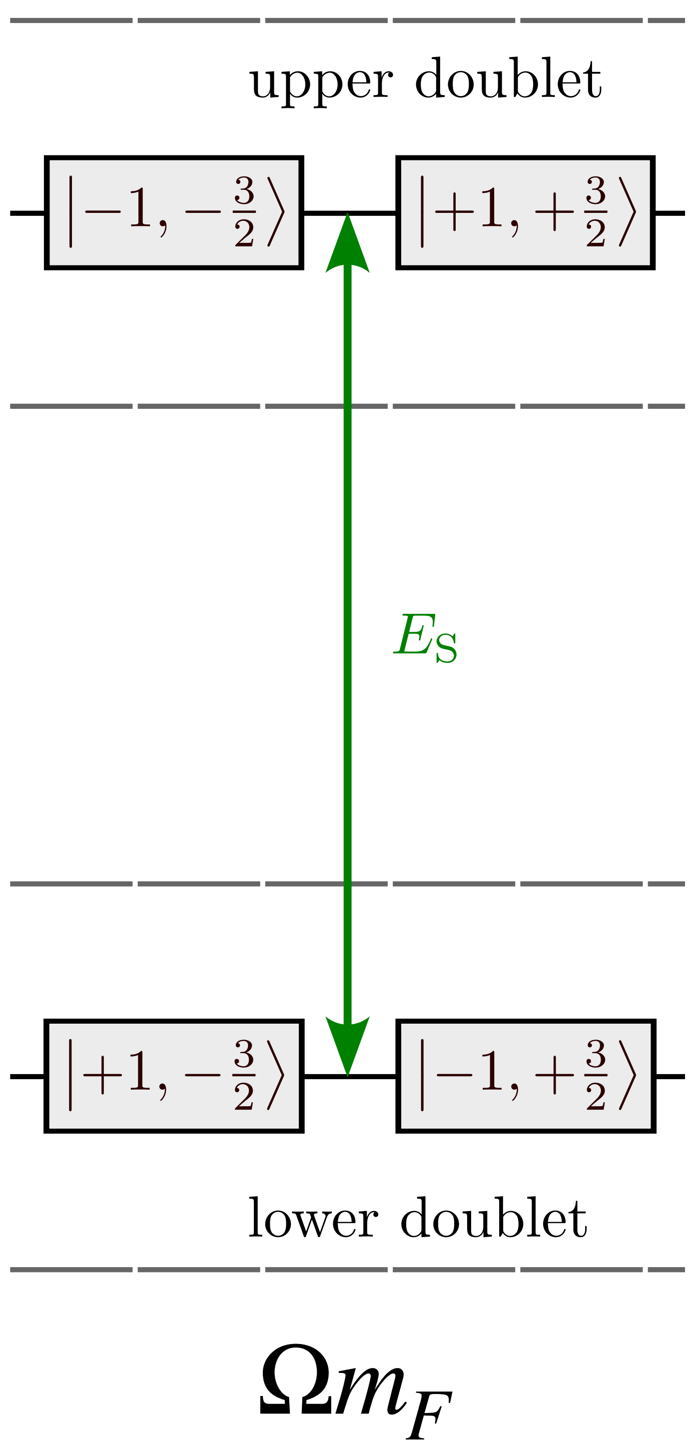

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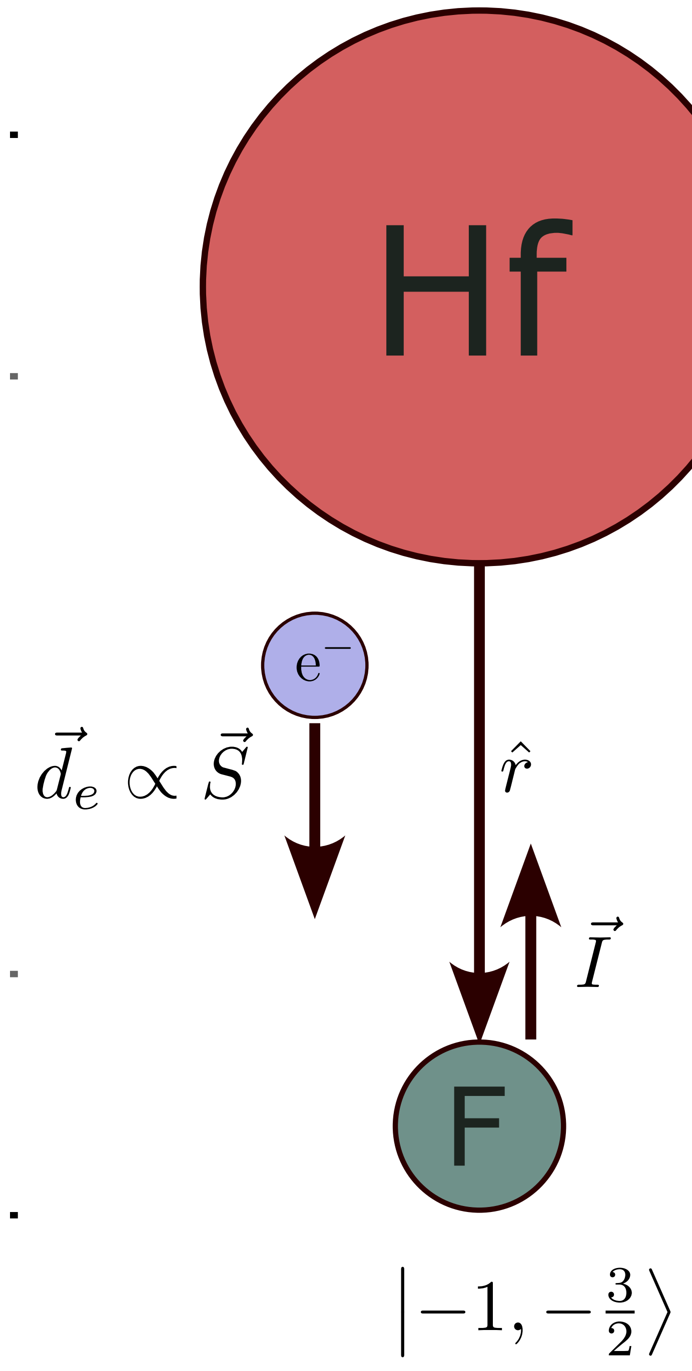

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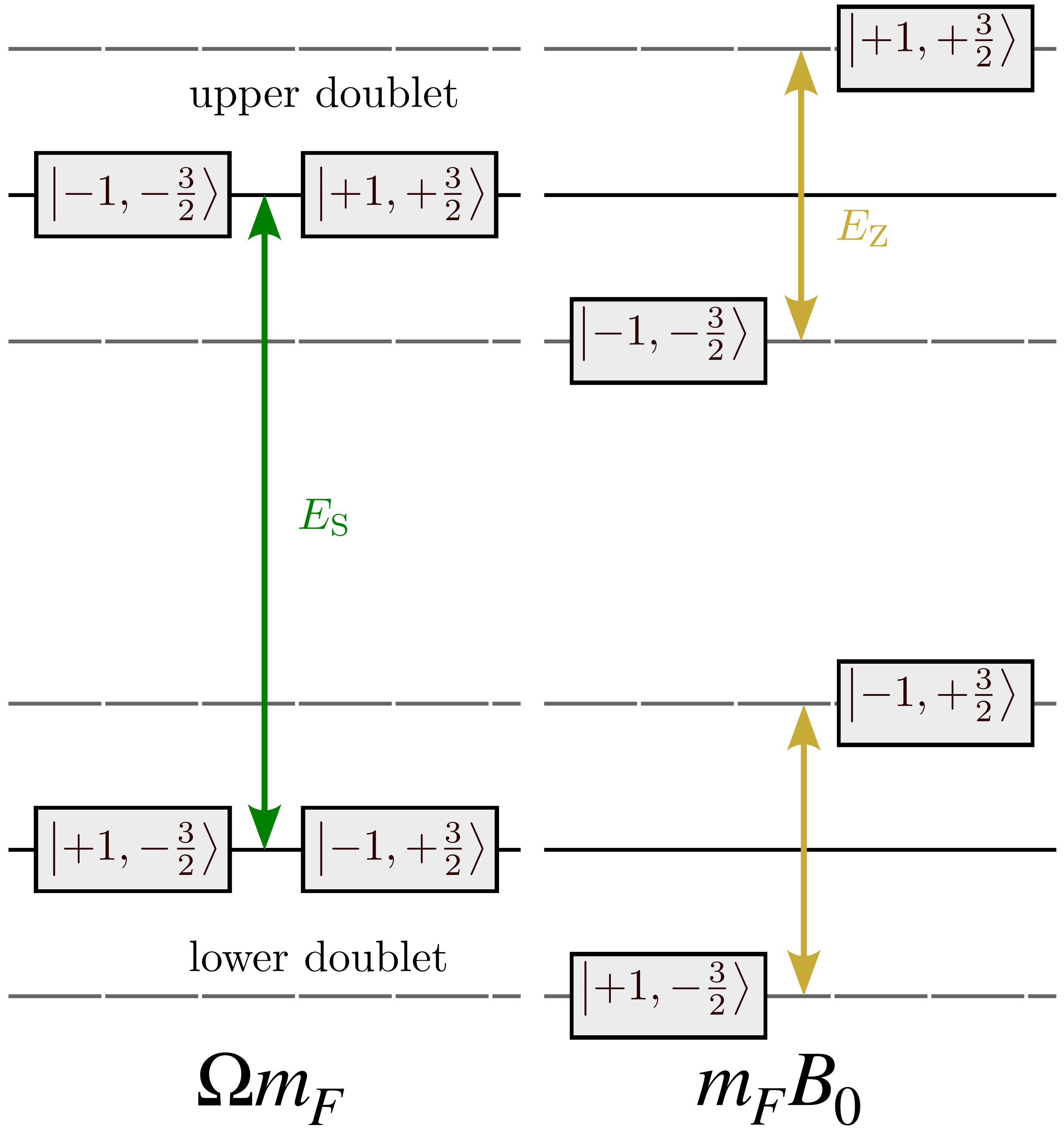

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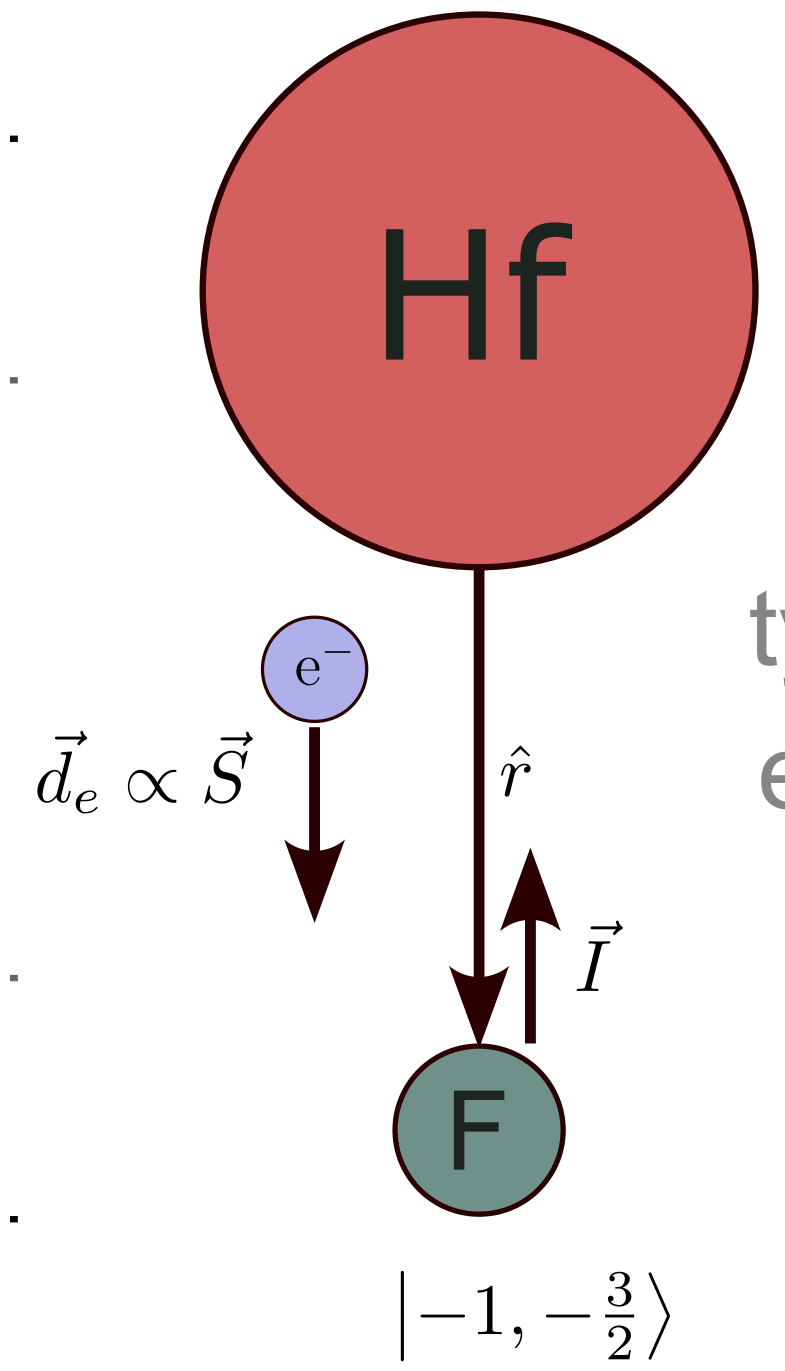

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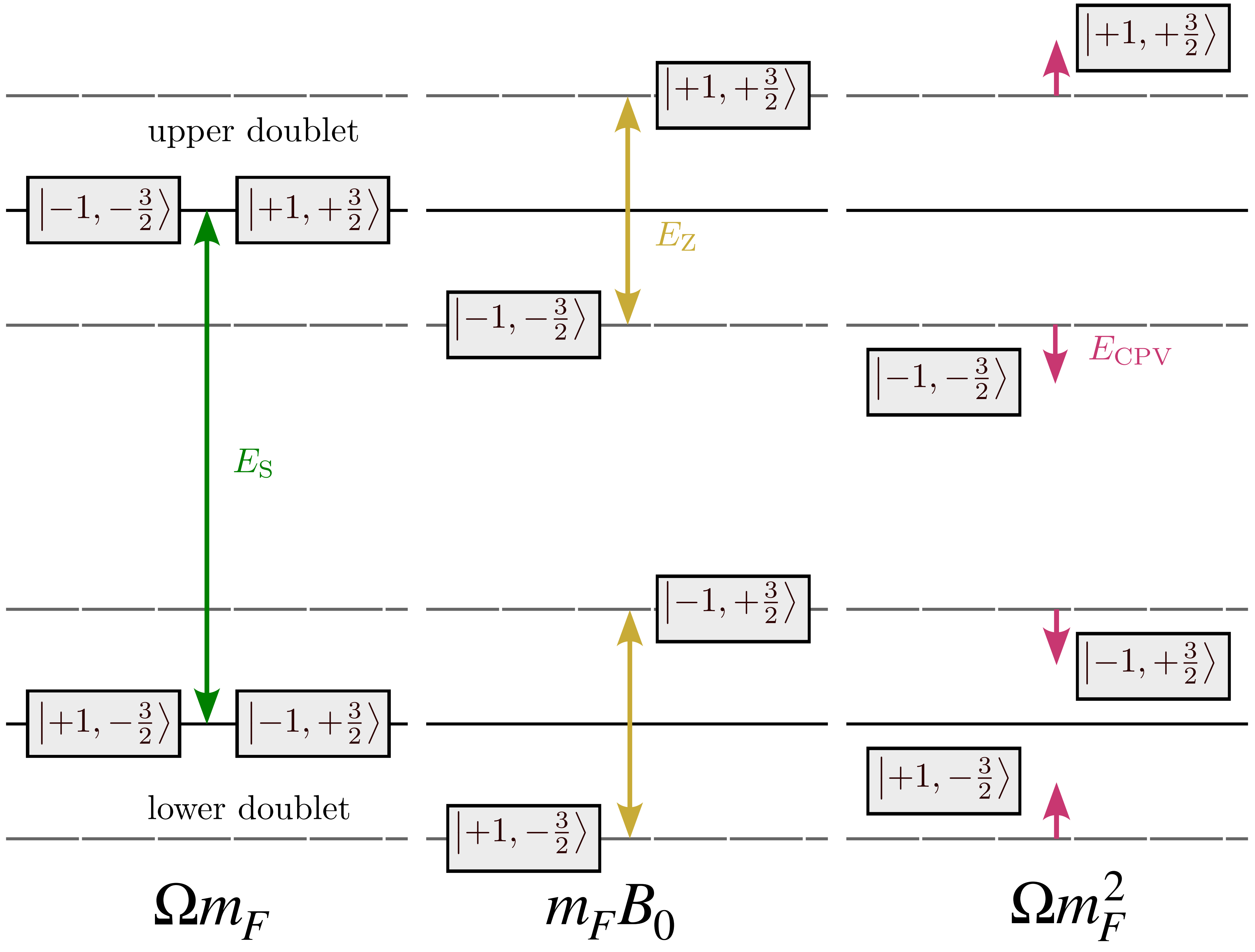

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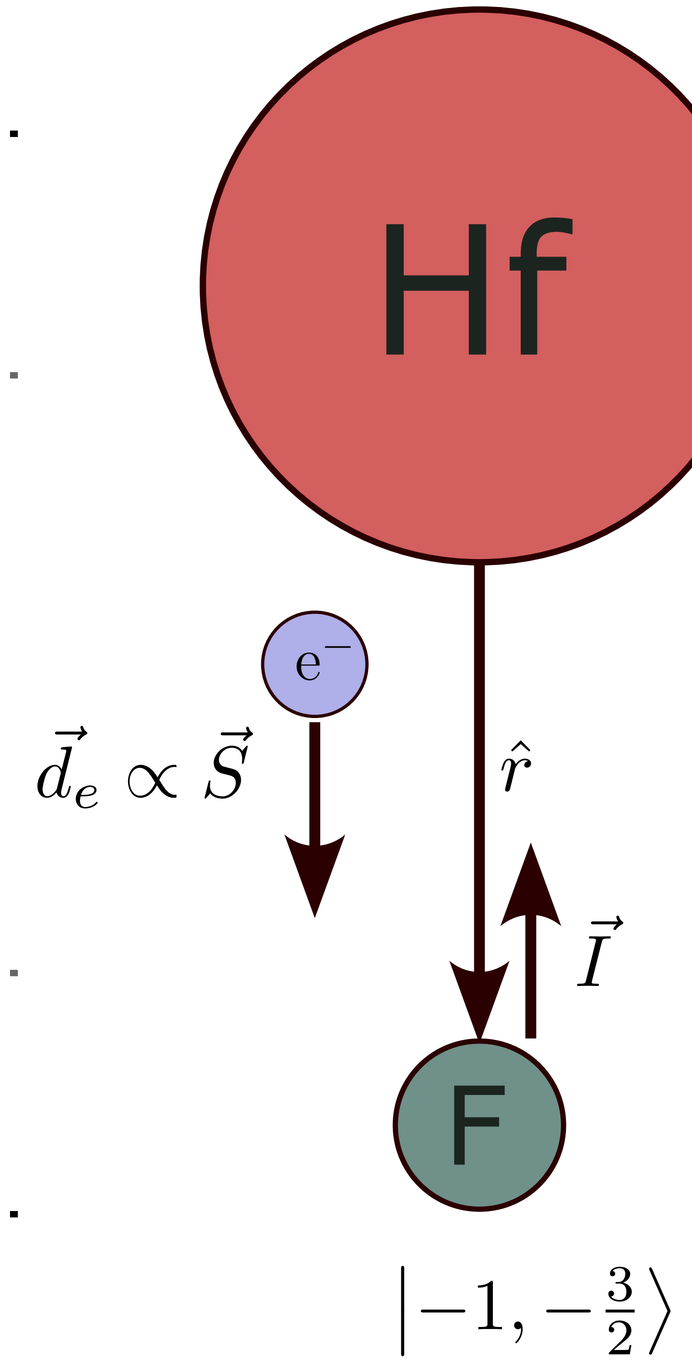

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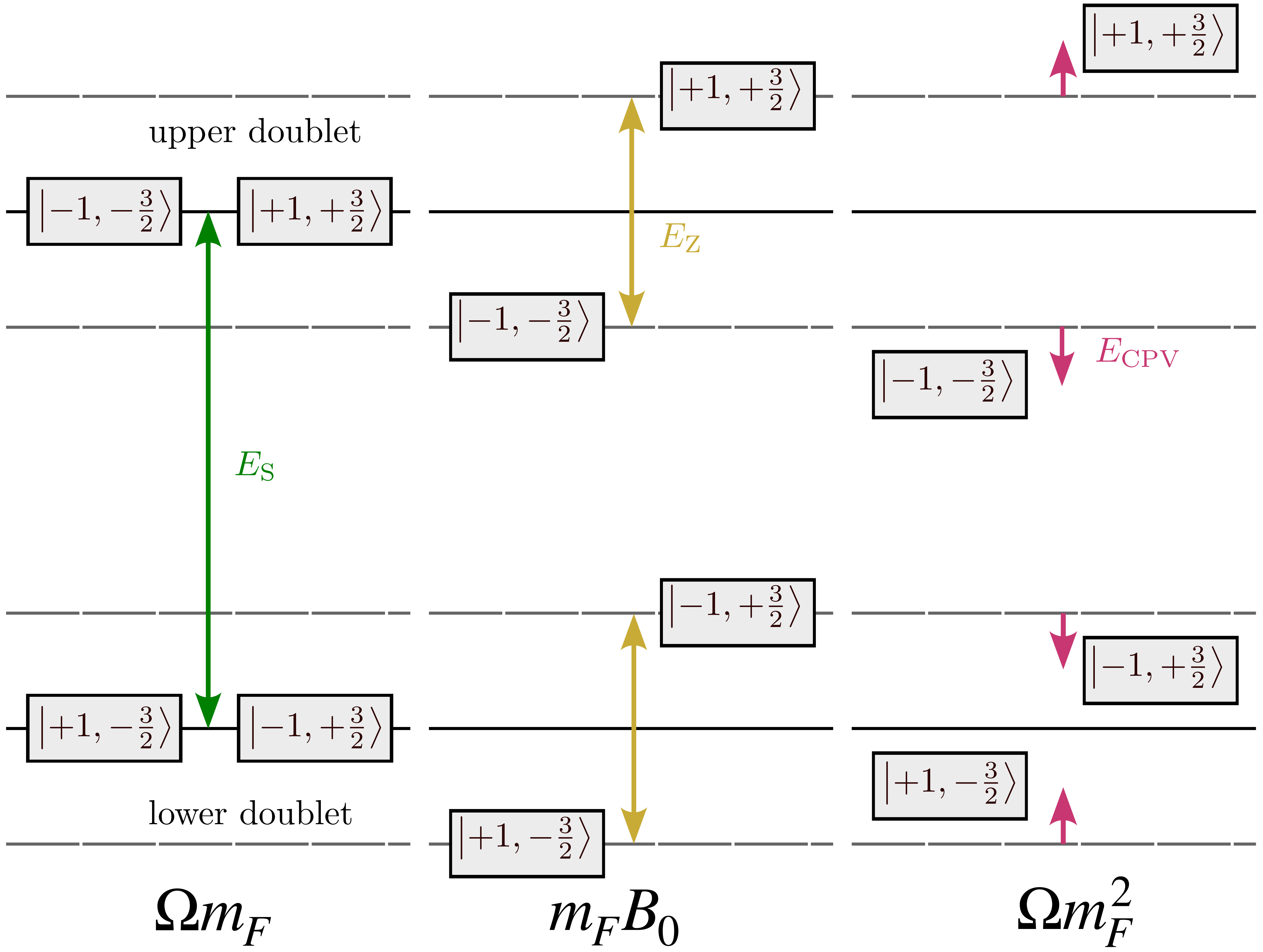

$|\Omega, m_F\rangle$ - the quantum states
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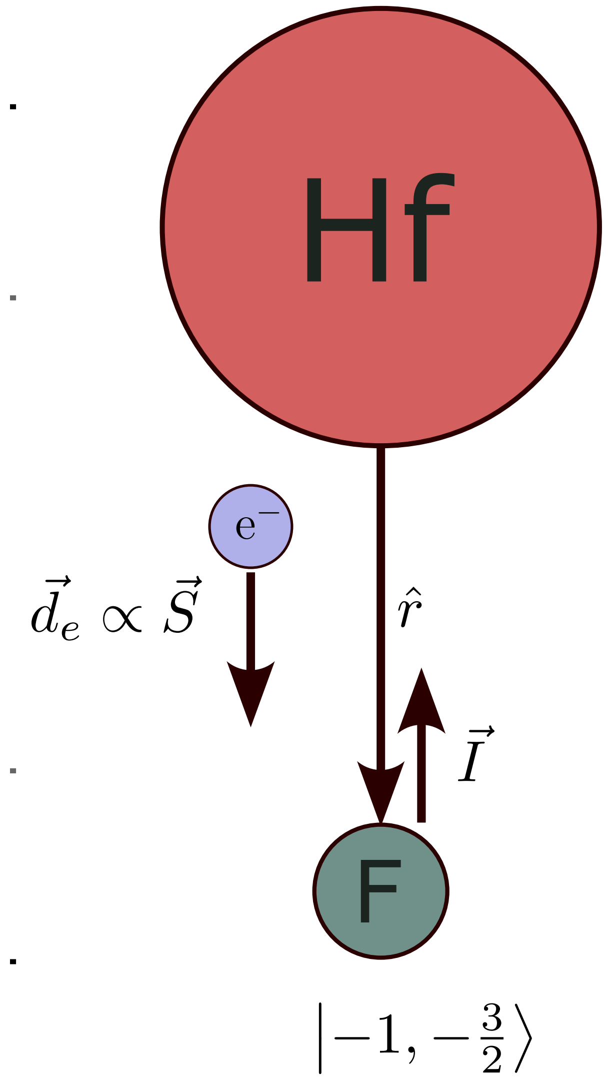
$$E_\mathrm{CPV} = \frac{\left(E_{+1,+\frac{2}{3}} - E_{-1,-\frac{2}{3}}\right) - \left(E_{-1,+\frac{2}{3}} - E_{+1,-\frac{2}{3}}\right)}{4} = \mathscr{E}_\mathrm{eff} d_e + V_\mathrm{SP} + \ldots$$

Baruch, Changala, Shagam, YS, PRL 24

CP violation in diatomic molecules



$$V_{\mathrm{SP}} \propto g_{\mathrm{S}}^{\psi_1} g_{\mathrm{P}}^{\psi_2} \frac{\vec{\sigma}^{\psi_1} \cdot \hat{r}}{2m_N} \left(\frac{1}{r} + m_\phi\right) \frac{e^{-m_\phi r}}{r}$$

Baruch, Changala, Shagam, YS, PRL 24

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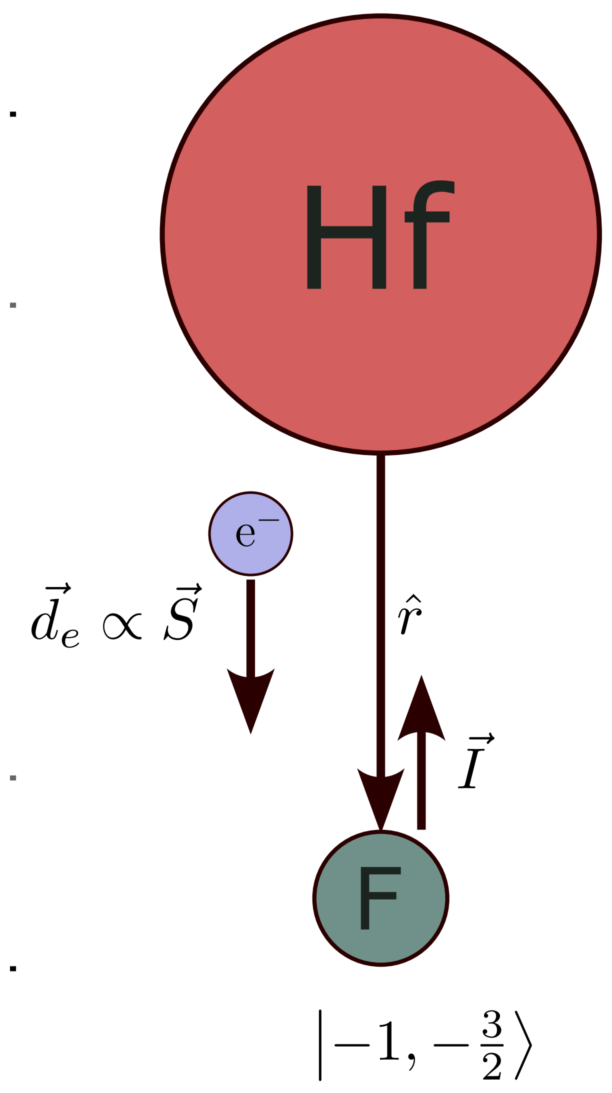

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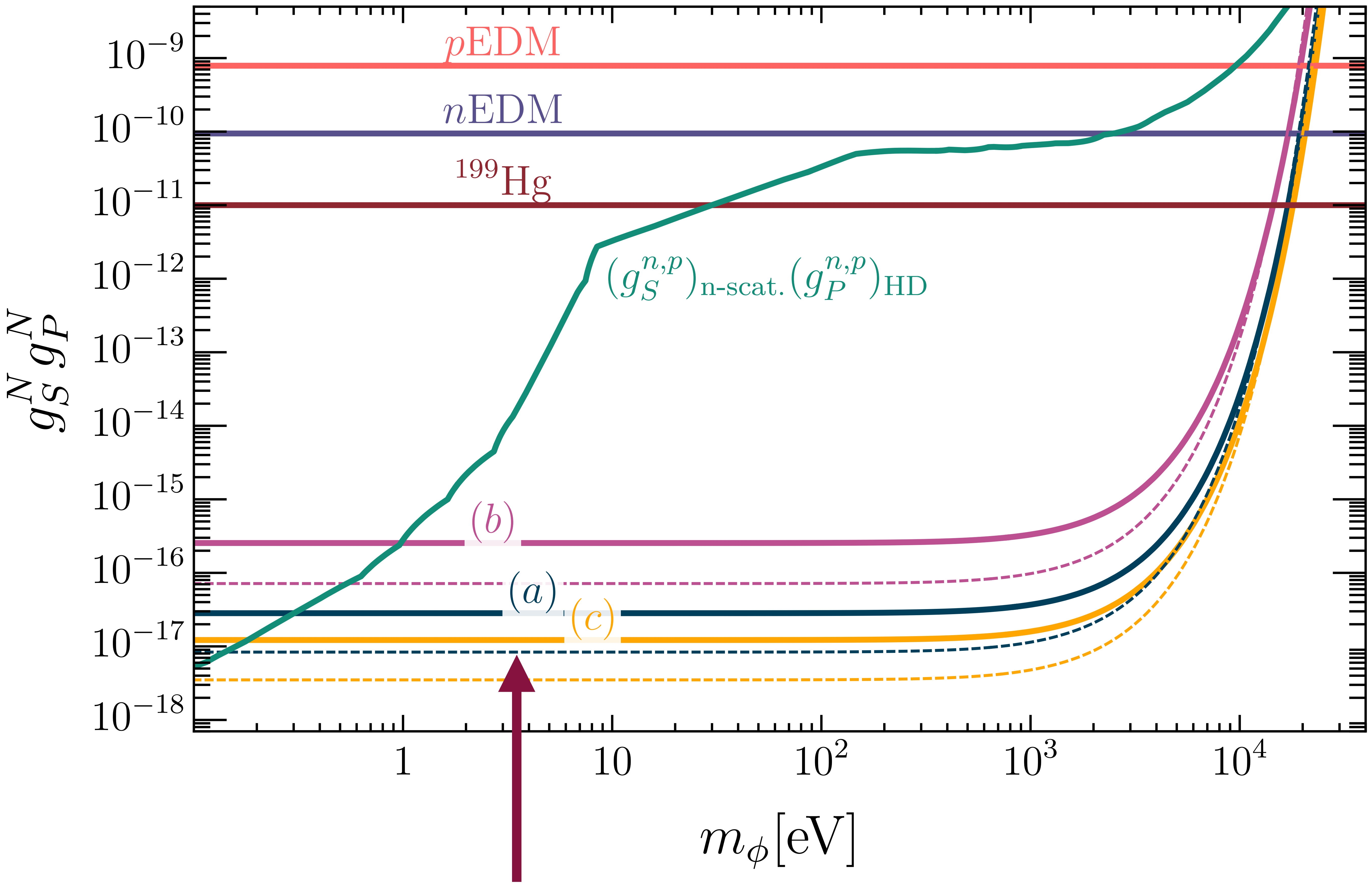
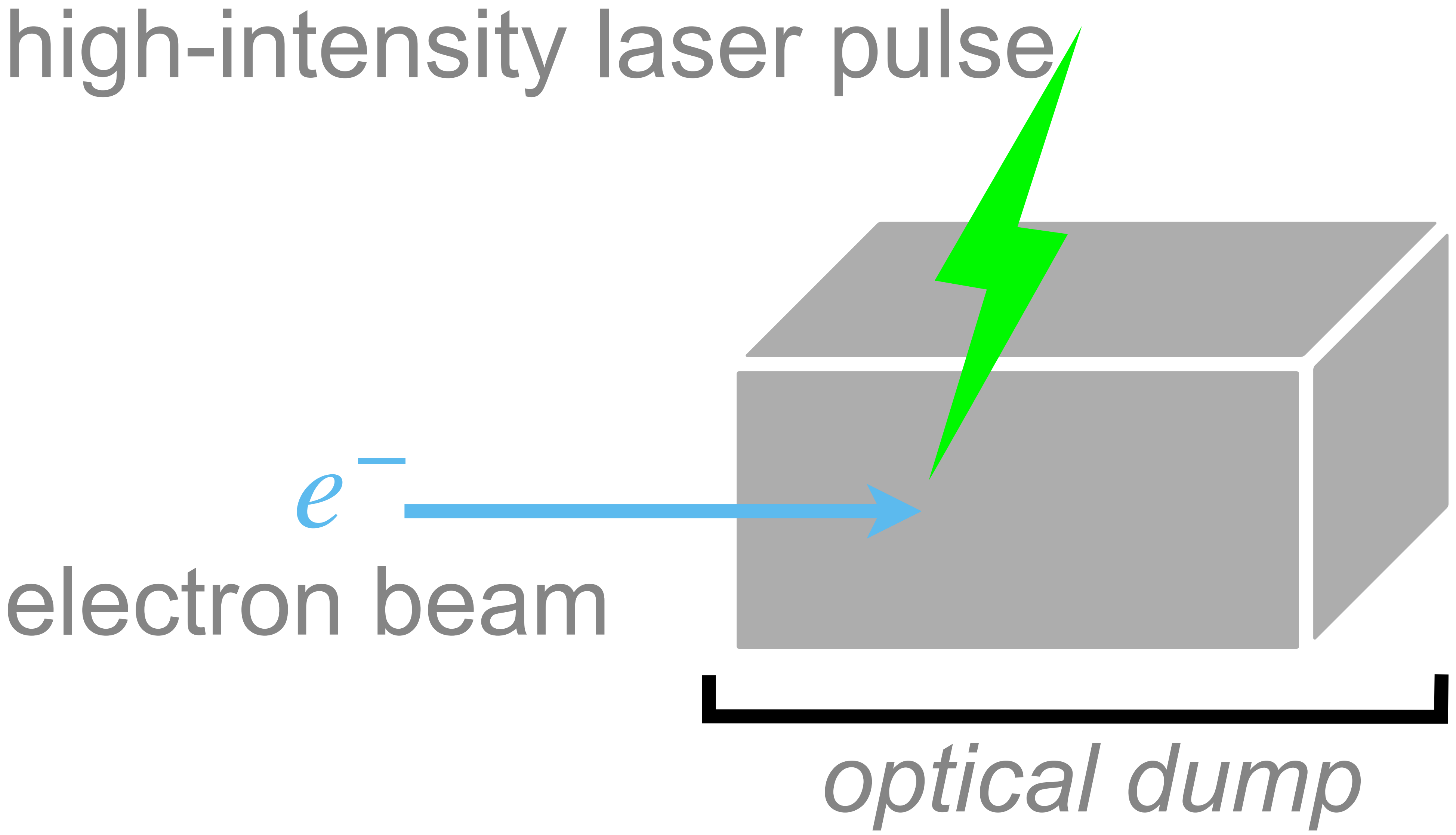


Molecules are the best terrestrial probe of long range hadronic CPV force

Baruch, Changala, Shagam, YS, PRL 24

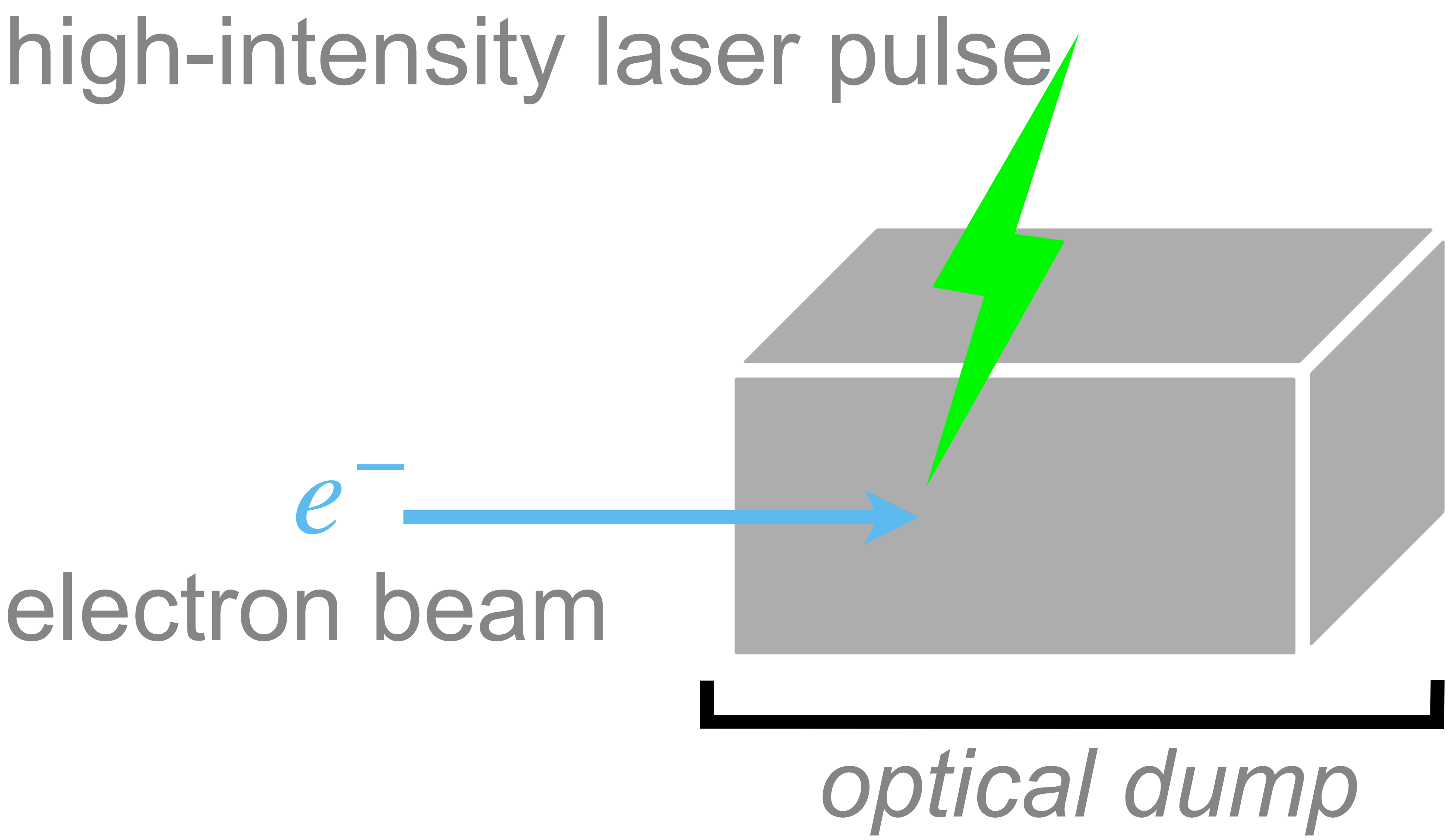
Future probes of scalars and axions at the intensity frontier Optical Dump and EIC

An optical dump



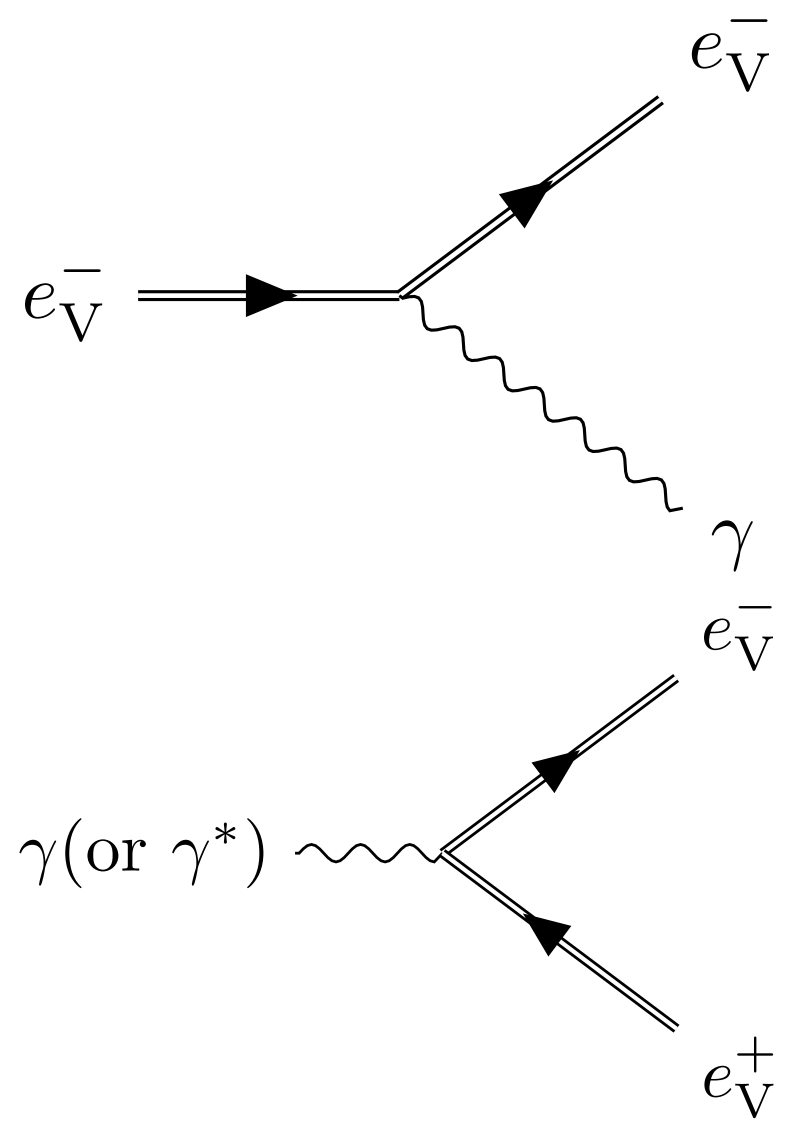
LOI 1909.00860 ,CDR 2102.02032

An optical dump



$E_e \approx 16.5\,\mathrm{GeV},\, \omega_\mathrm{L} \approx 1.5\,\mathrm{eV} \sim 1/(0.4\,\mathrm{fs}),\;\; t_\mathrm{L} \sim \mathcal{O}(10 - 100)\,\mathrm{fs}$

LUXE



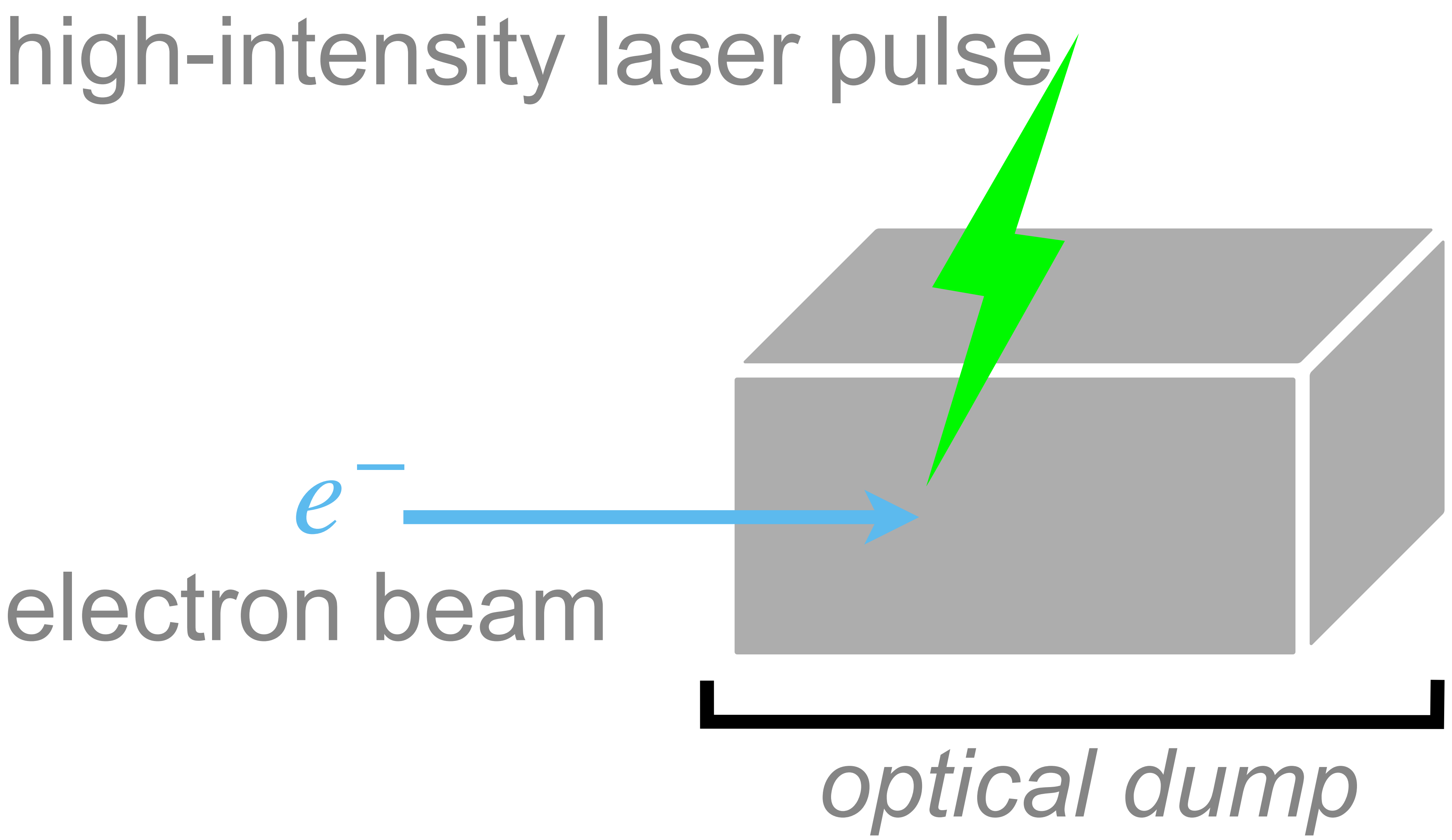
$\tau_\gamma \sim \mathcal{O}(10)\mathrm{fs}$

$\tau_{ee} \sim \mathcal{O}(10^4 - 10^6)\mathrm{fs}$

Schwinger like pair production
the main physics goal

LOI 1909.00860 ,CDR 2102.02032

An optical dump



high-intensity laser pulse

e^-

electron beam

optical dump

$E_e \approx 16.5\,\mathrm{GeV},\ \omega_\mathrm{L} \approx 1.5\,\mathrm{eV} \sim 1/(0.4\,\mathrm{fs}),\ \ t_\mathrm{L} \sim \mathcal{O}(10-100)\,\mathrm{fs}$

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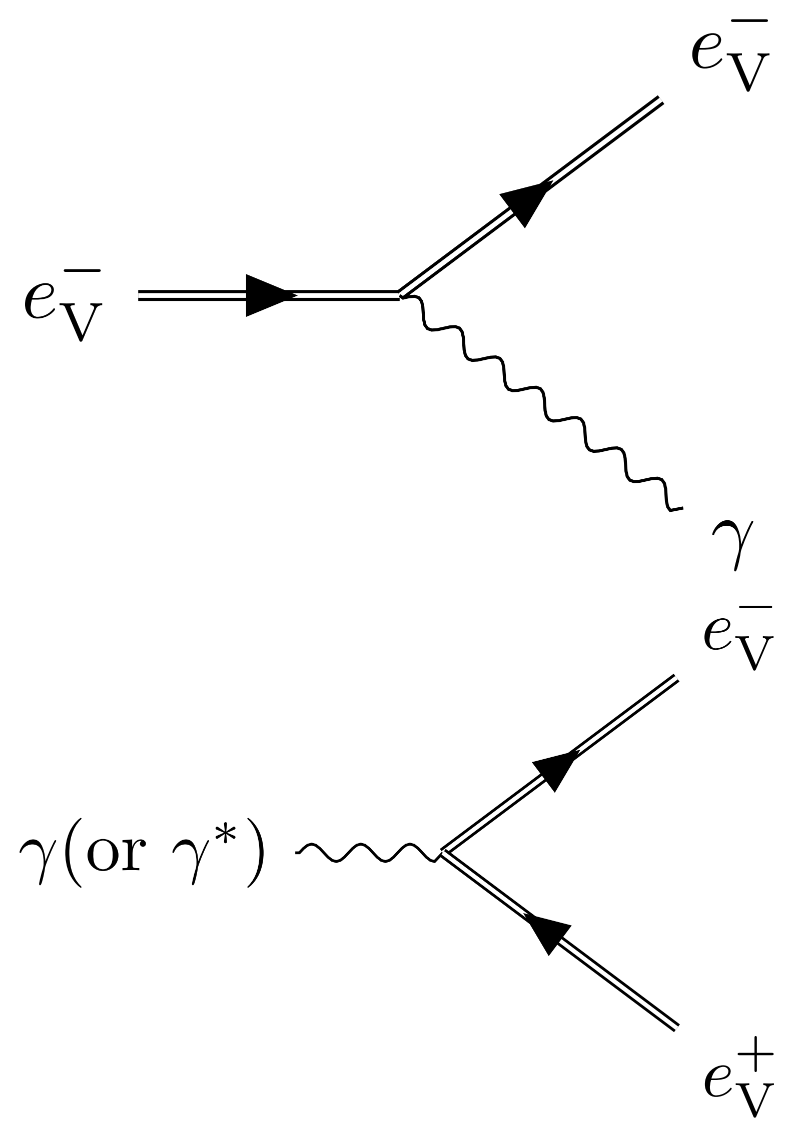


$\tau_\gamma \sim \mathcal{O}(10)\mathrm{fs}$

$\boxed{1/\omega_\mathrm{L} \ll \tau_\gamma \lesssim t_\mathrm{L} \ll \tau_{ee}}$

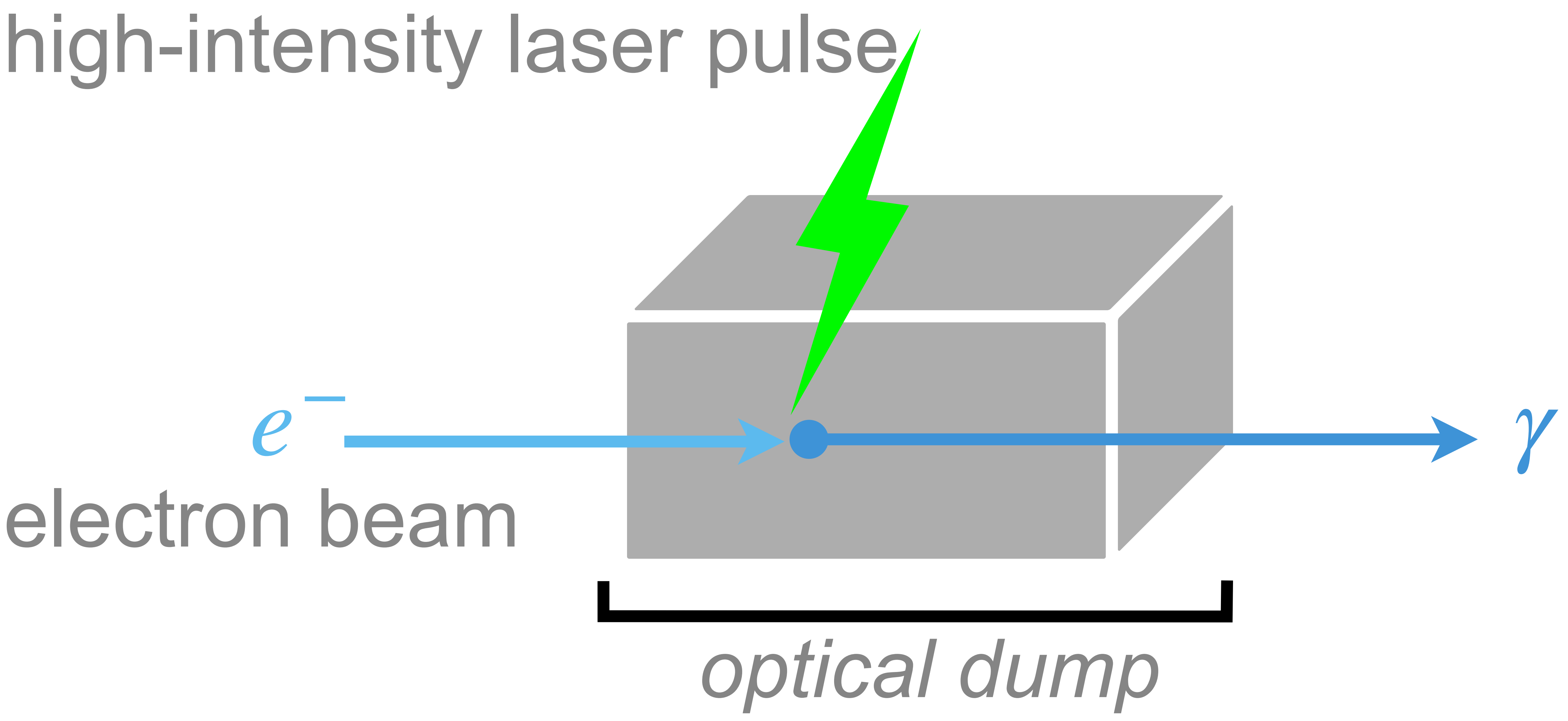
$\tau_{ee} \sim \mathcal{O}(10^4 - 10^6)\mathrm{fs}$

Schwinger like pair production
the main physics goal

in ordinary material $\tau_\gamma \sim \tau_{ee}$

LOI 1909.00860 ,CDR 2102.02032

An optical dump

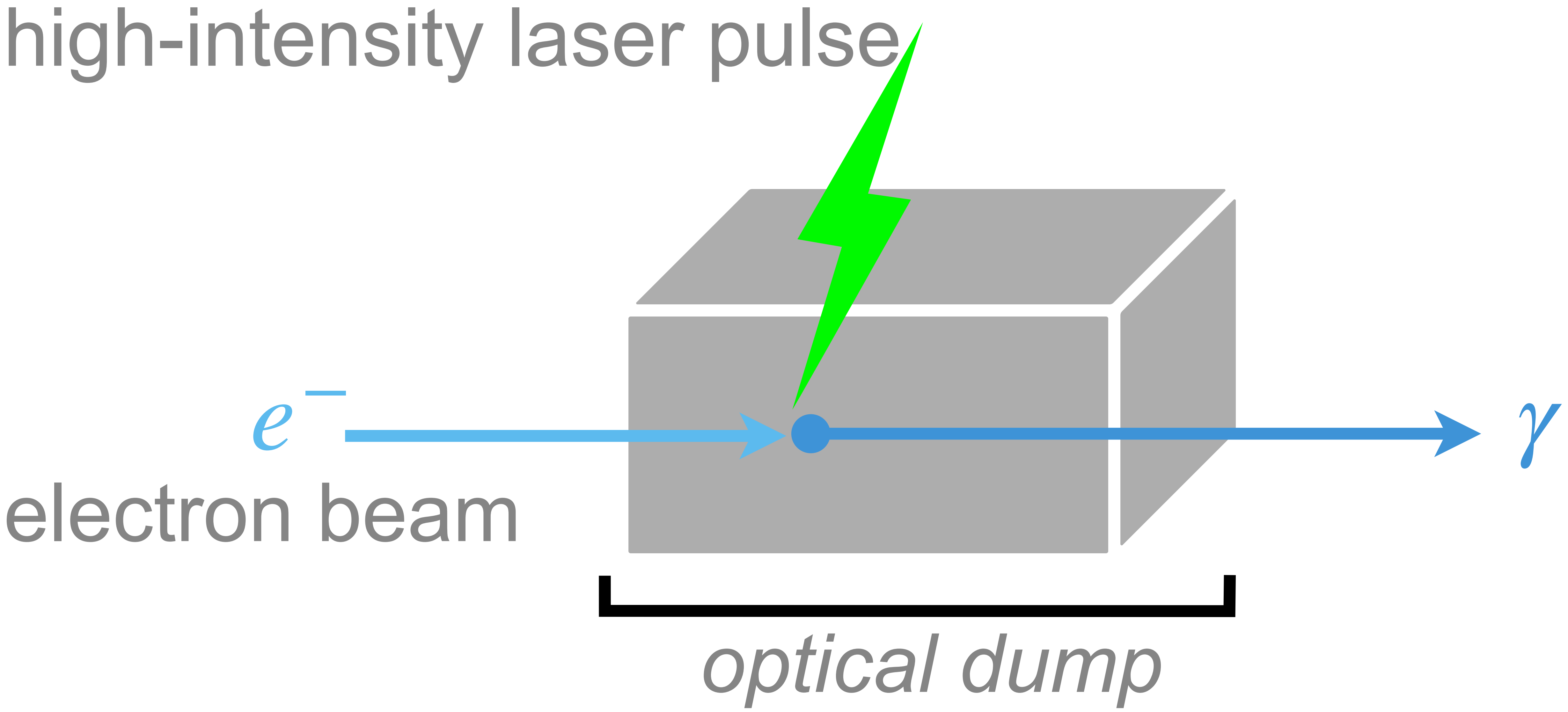


photon emission, frequent process

several outgoing photons per electron

LOI 1909.00860 ,CDR 2102.02032

An optical dump



photon emission, frequent process
several outgoing photons per electron

LUXE =

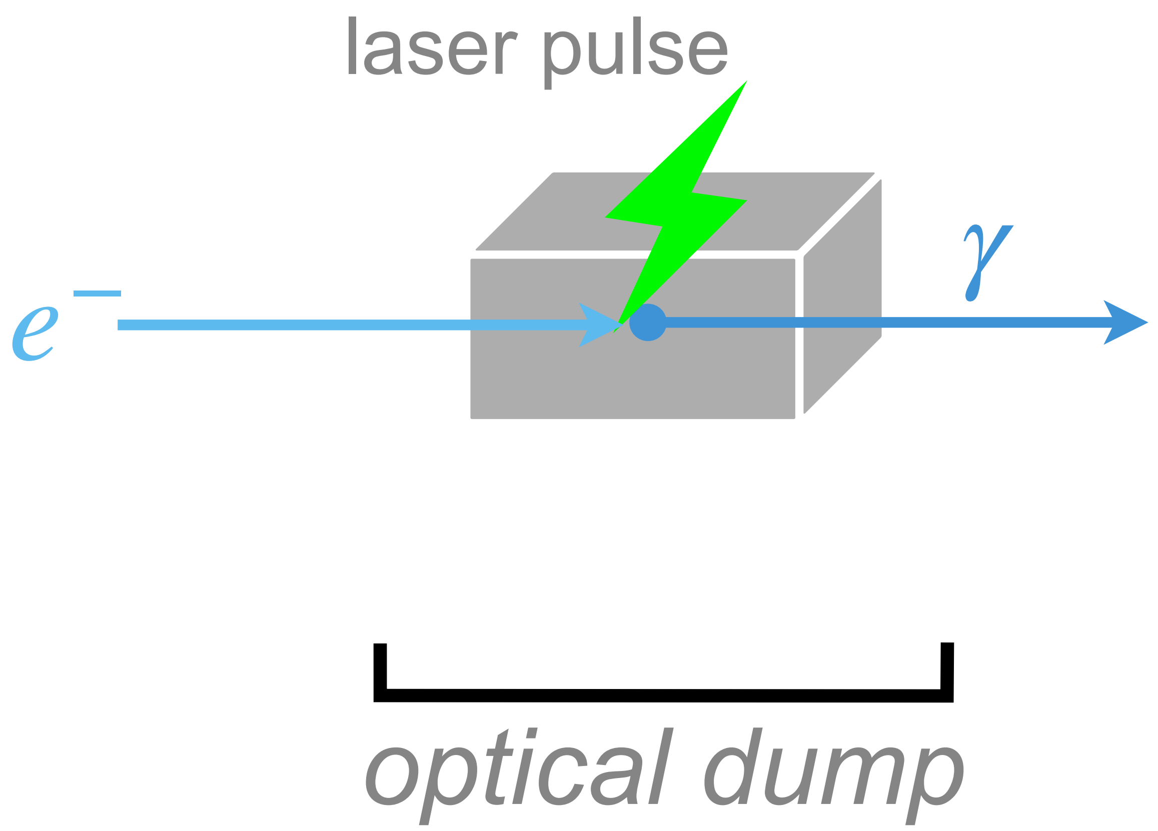
high intensity and high energy
collimated photon source
$10^{10}\,\gamma/\mathrm{sec},\ E_\gamma \sim \mathcal{O}(m_p)$

LOI 1909.00860 ,CDR 2102.02032

Bai, Blackburn, Borysov, Davidi, Hartin,
Heinemann, Ma, Perez, YS, Tal Hod PRD 22

Axions at an optical dump

LUXE-NPOD
(new physics at optical dump)



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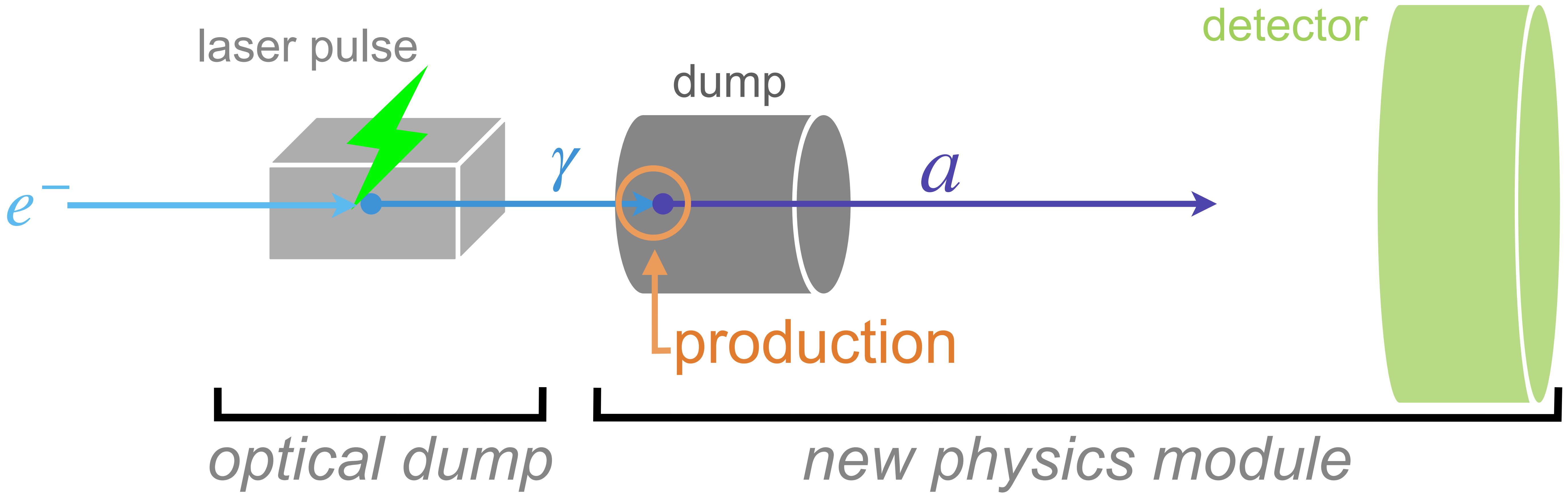

adopted by the
LUXE collaboration

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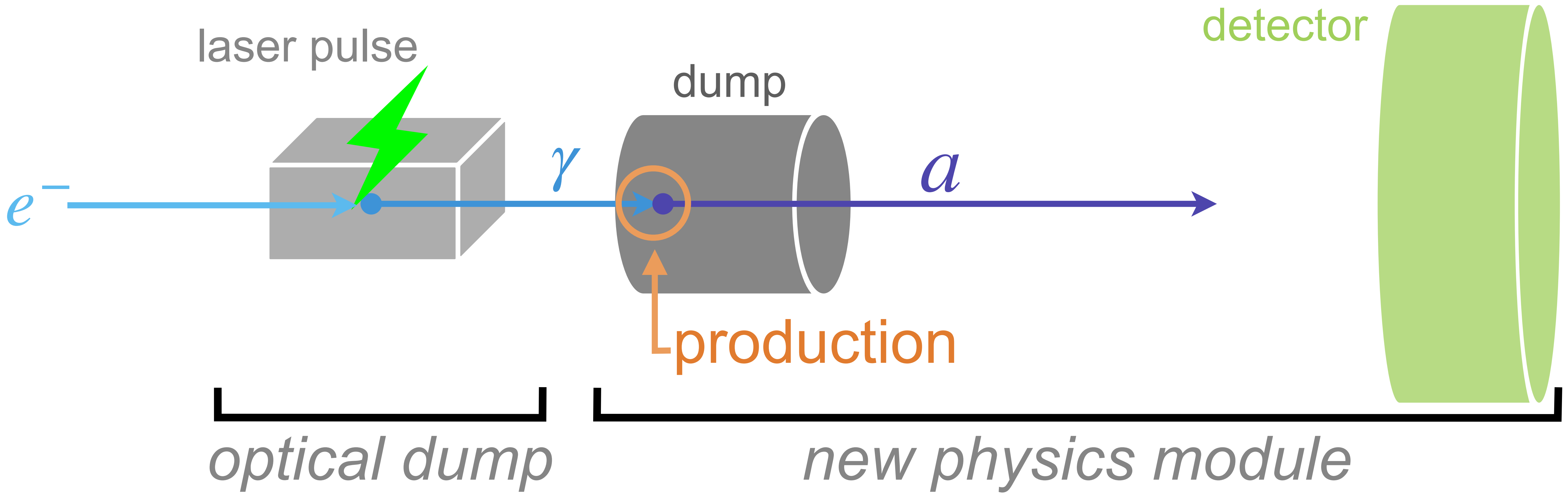

adopted by the
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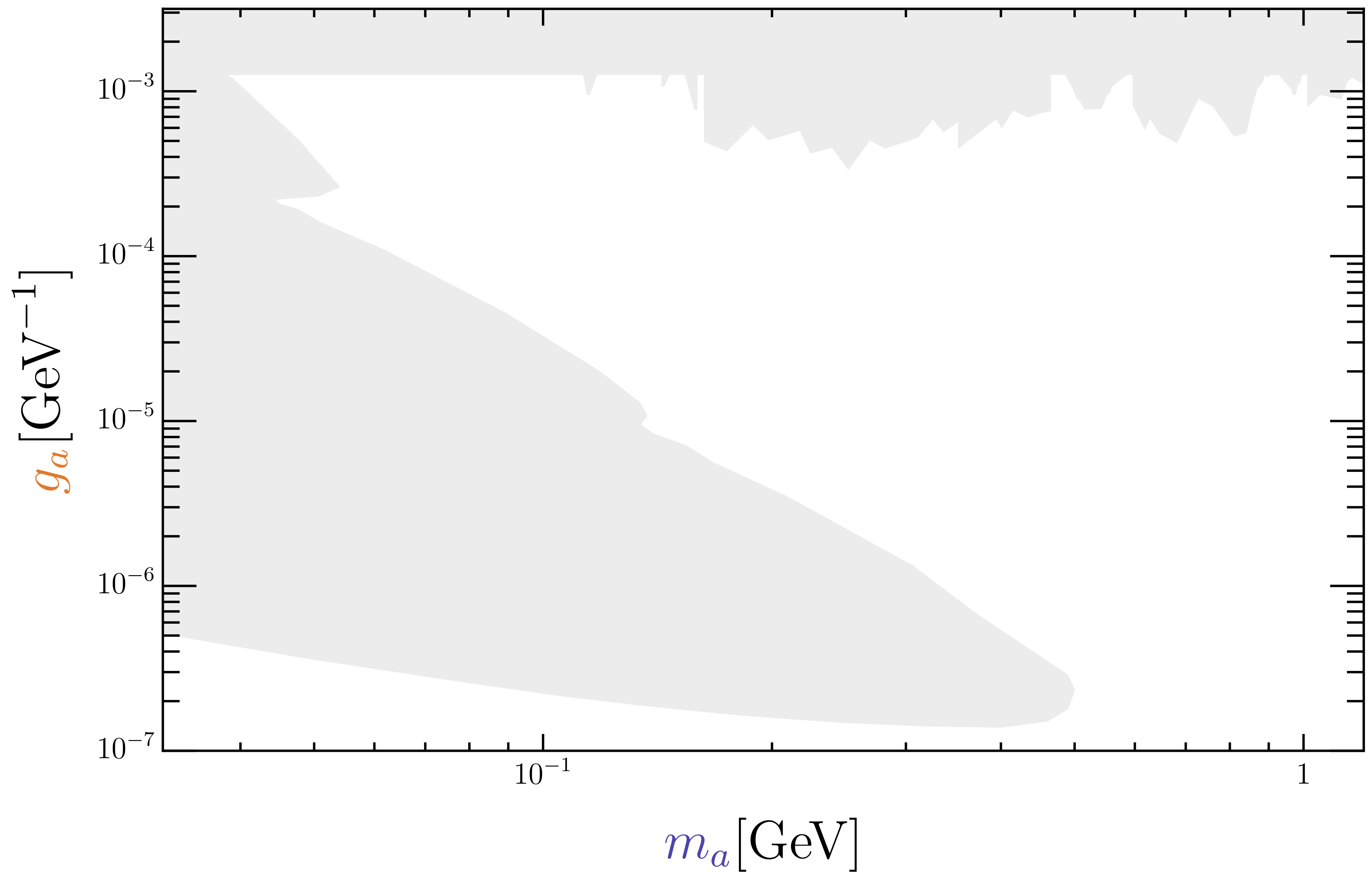
$$\frac{g_a}{4} a F_{\mu\nu}\tilde{F}^{\mu\nu}$$



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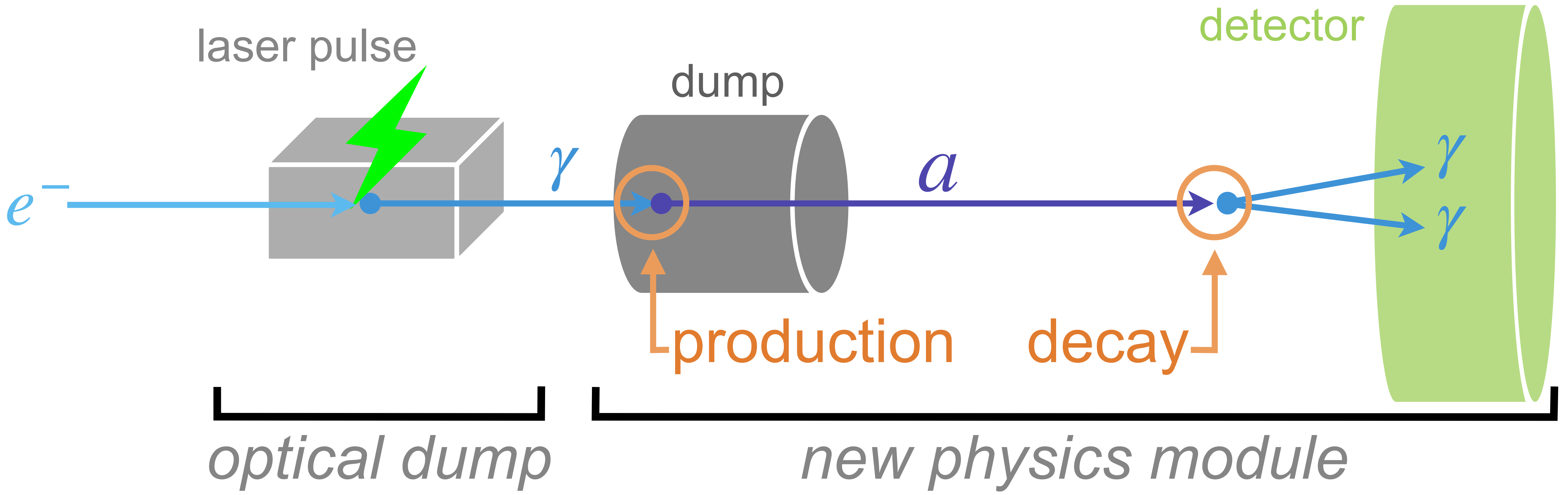

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LUXE collaboration

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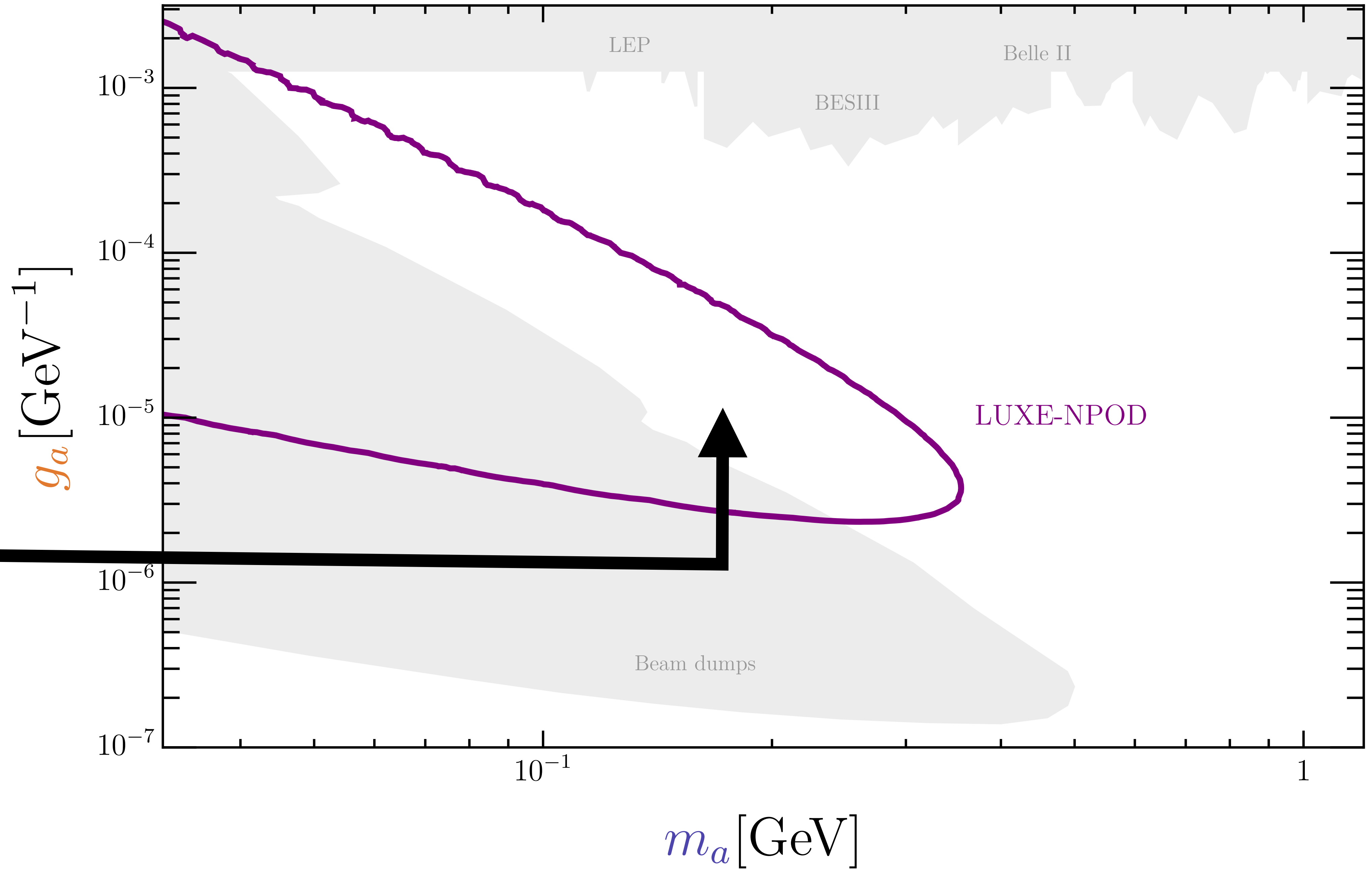
probe uncharted territory



very low
background rate

Bai, Blackburn, Borysov, Davidi, Hartin,
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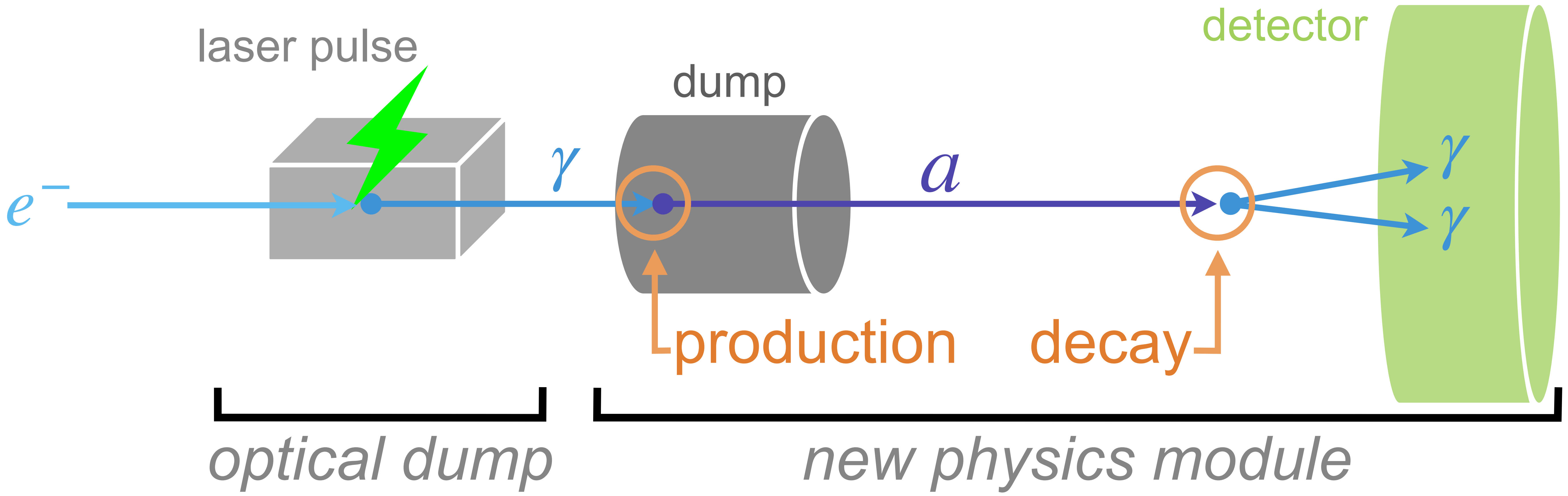

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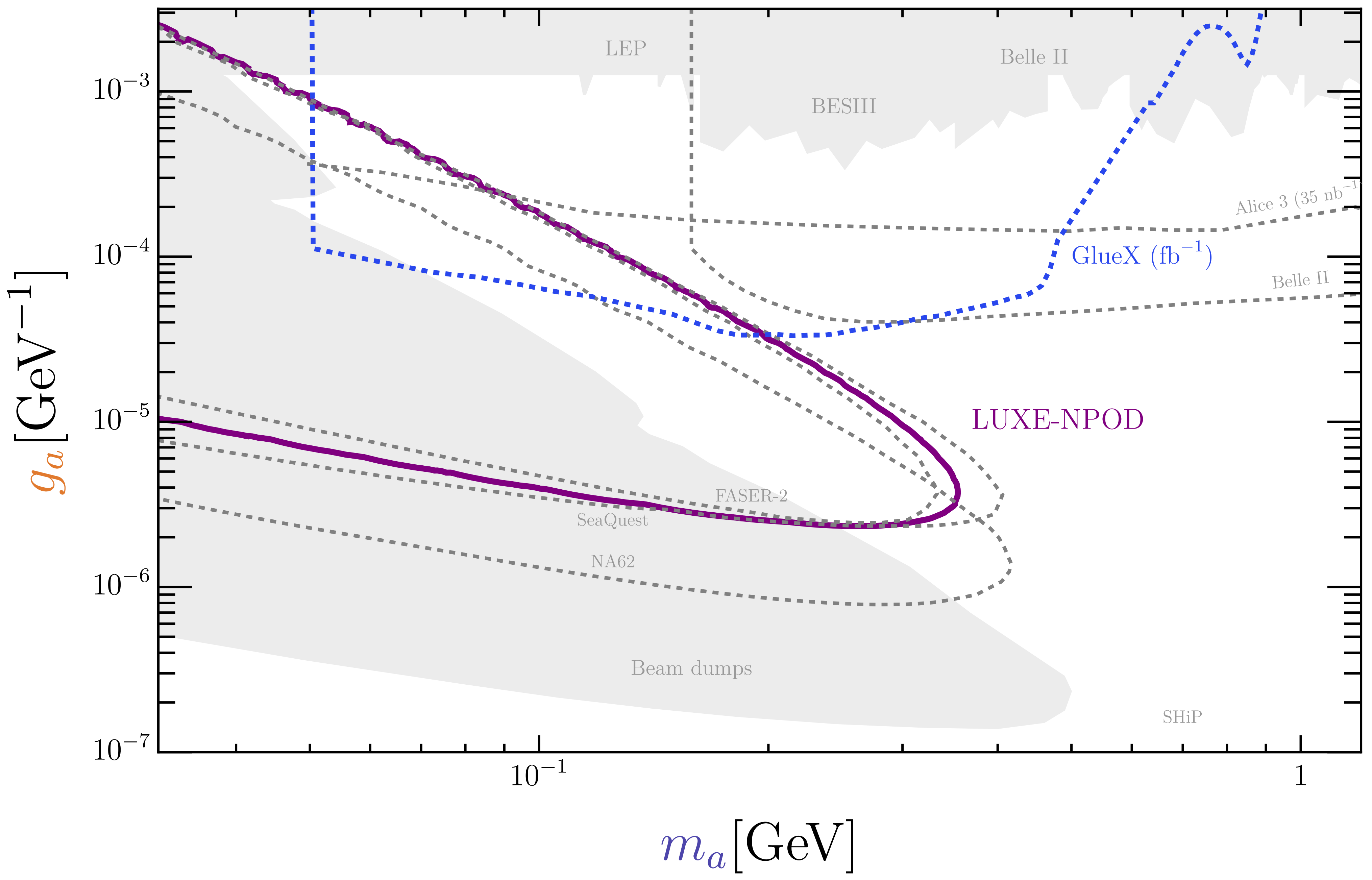


very low
background rate

applicable to:

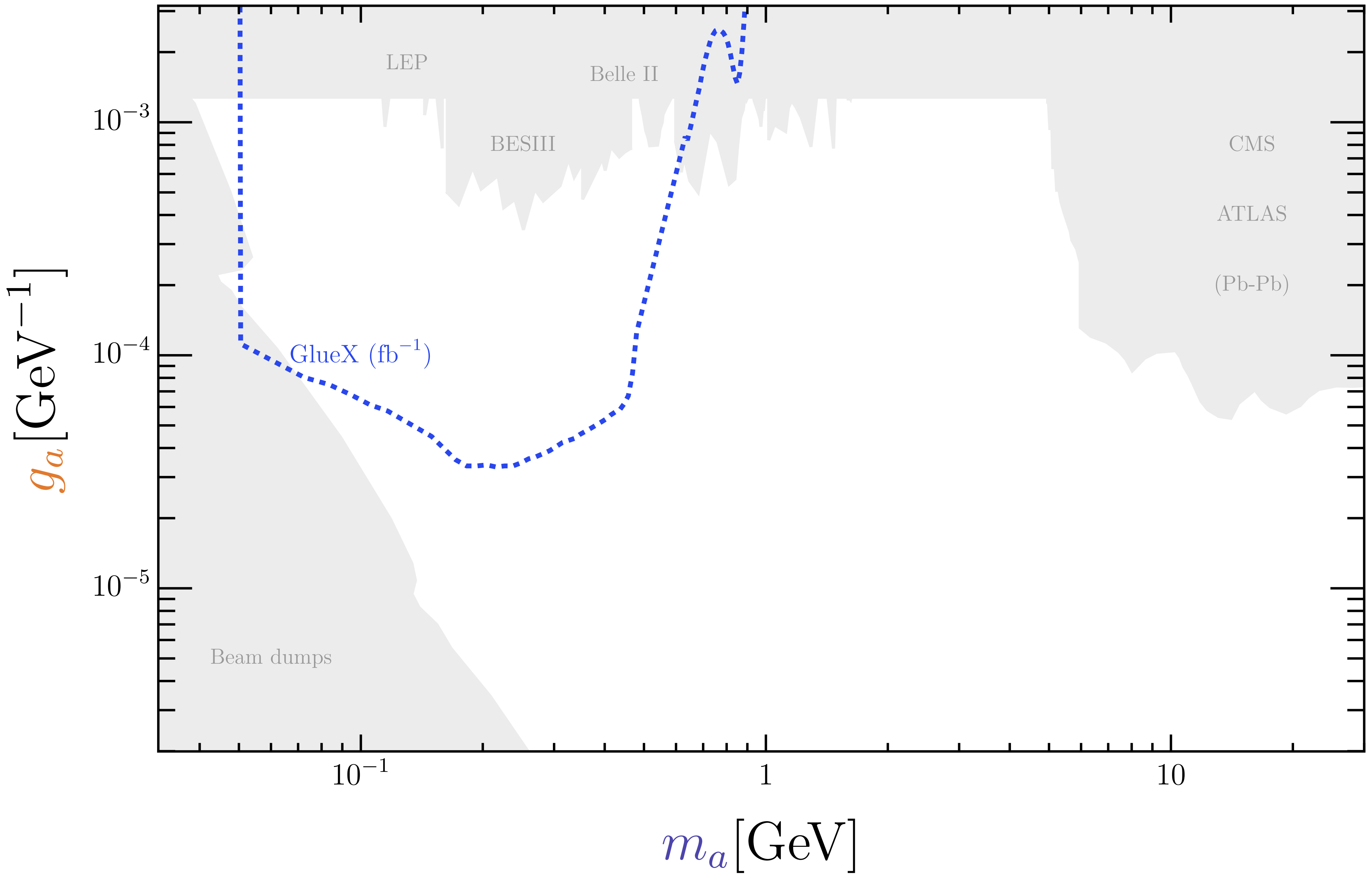
SLAC, LBNL, ILC….

GlueX: Aloni, Fanelli, YS, Williams, PRL 2019

Bai, Blackburn, Borysov, Davidi, Hartin,
Heinemann, Ma, Perez, YS, Tal Hod PRD 22

Axions at electron-ion collider (EIC)

How can we go further?

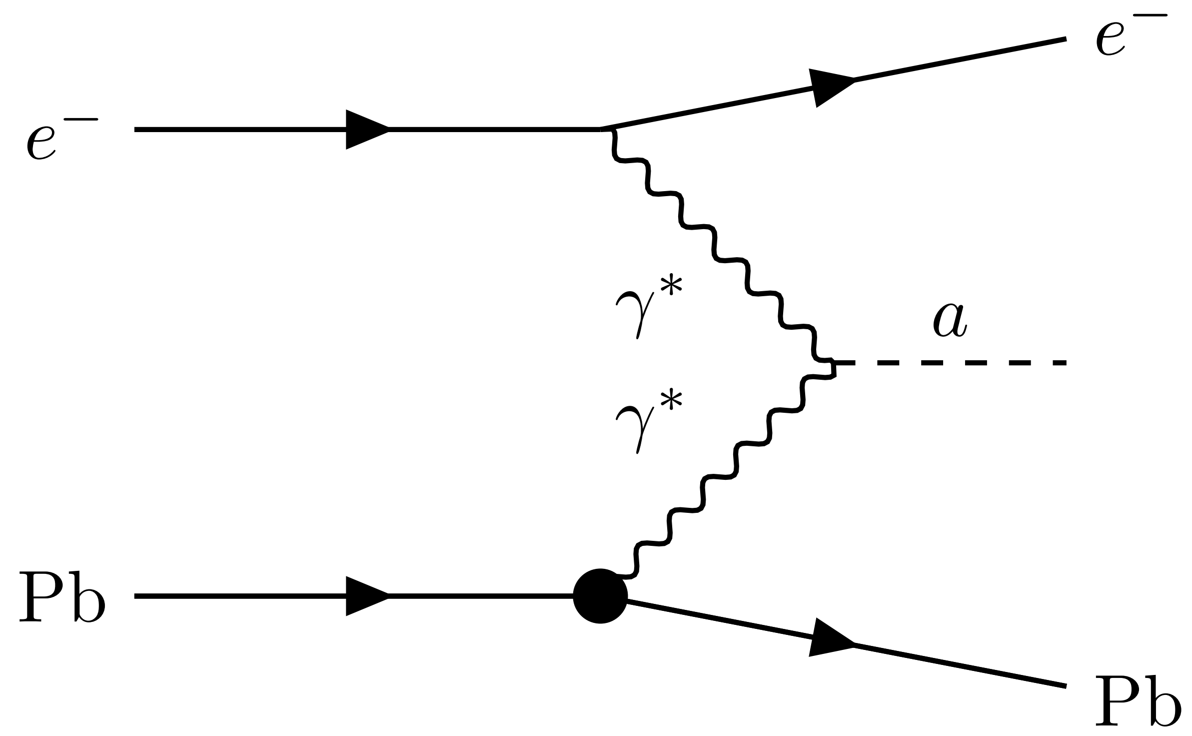


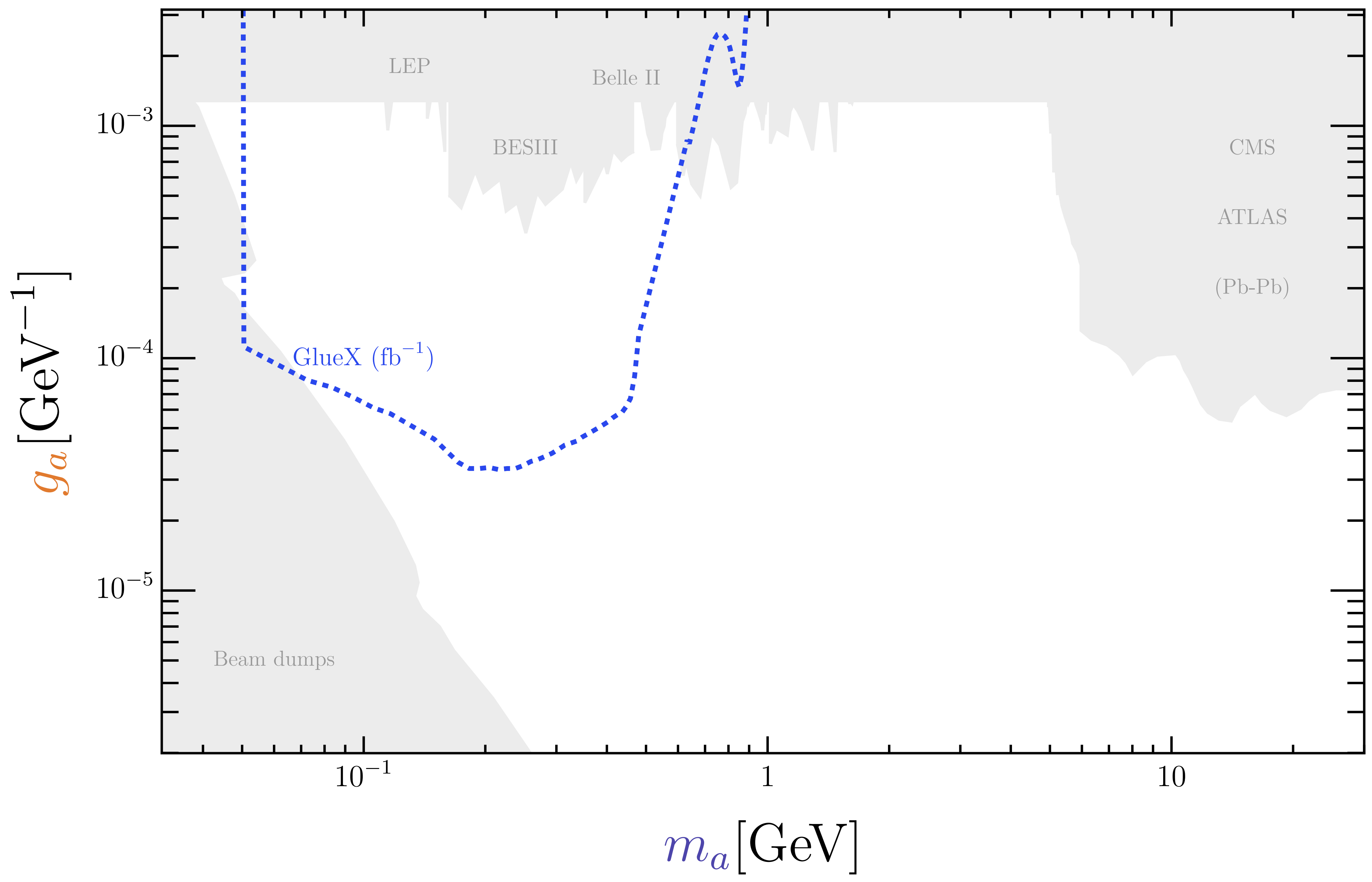
Balkin, Hen, Li, Liu, Ma, YS, Williams JHEP 24

Axions at electron-ion collider (EIC)

$E_e = 18\,\mathrm{GeV}$

$E_{\mathrm{Pb}} = 20\,\mathrm{TeV}$





Balkin, Hen, Li, Liu, Ma, YS, Williams JHEP 24

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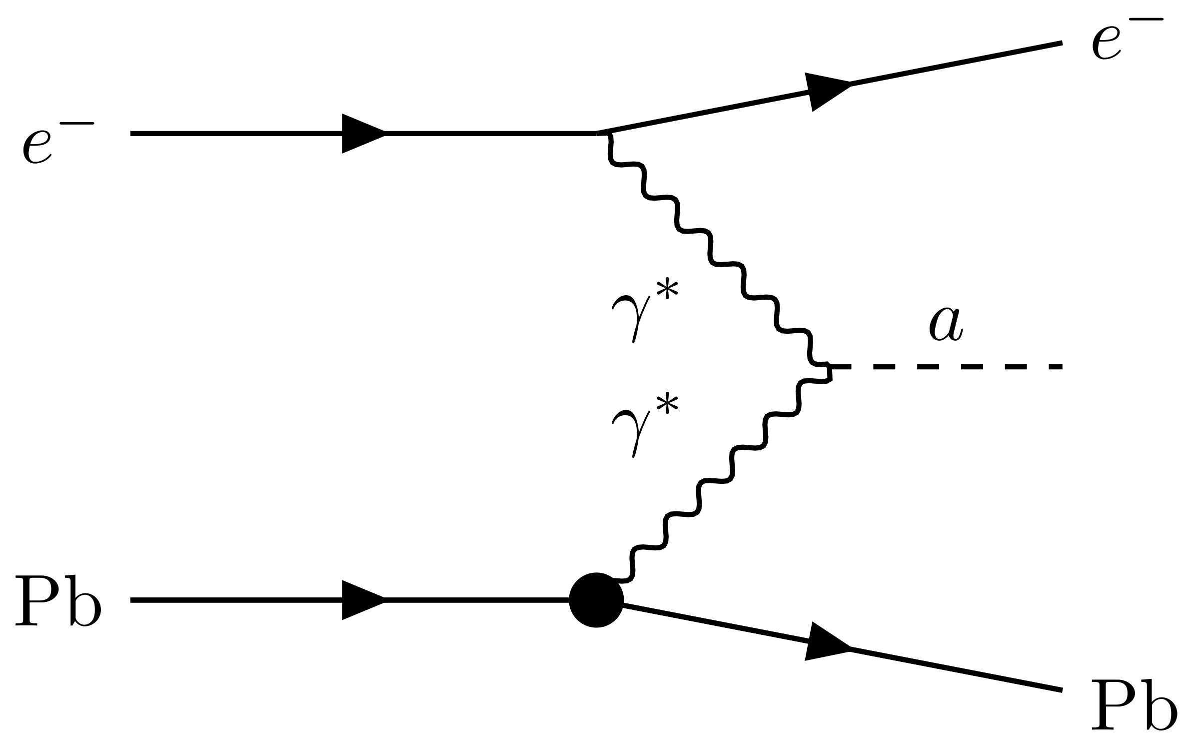
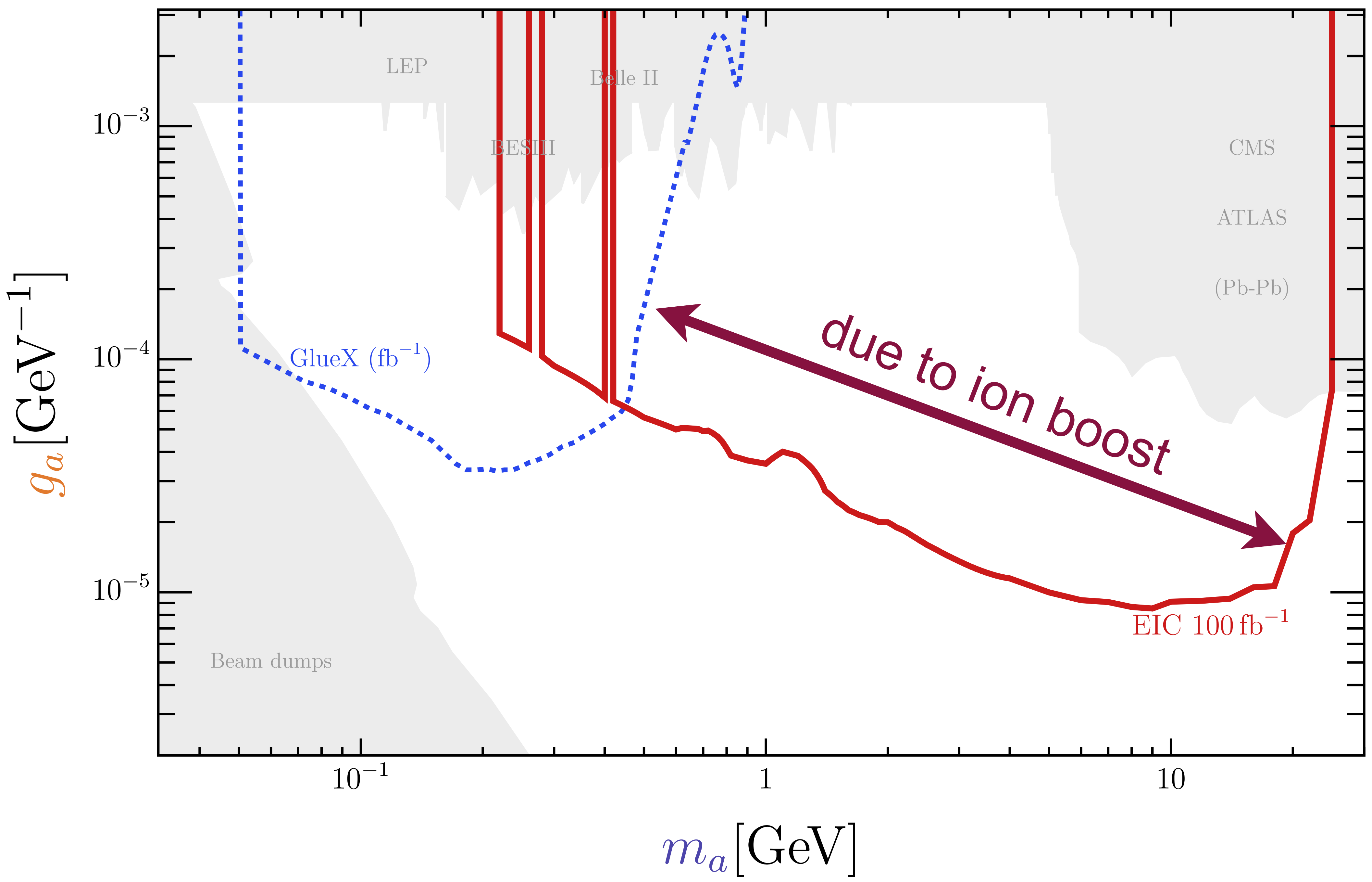


coherent production of new particles up to $m_a \sim 20\,\mathrm{GeV}$


prompt

due to ion boost

axion is produced and promptly decays to photons

Balkin, Hen, Li, Liu, Ma, YS, Williams JHEP 24

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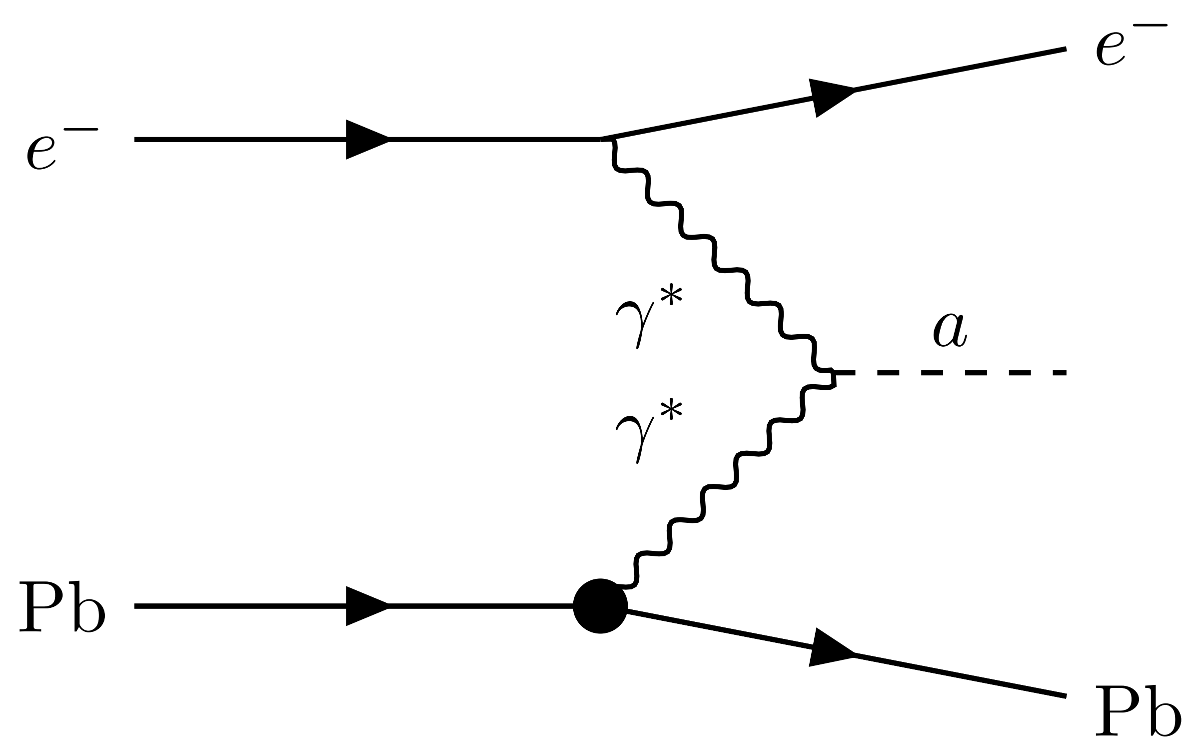

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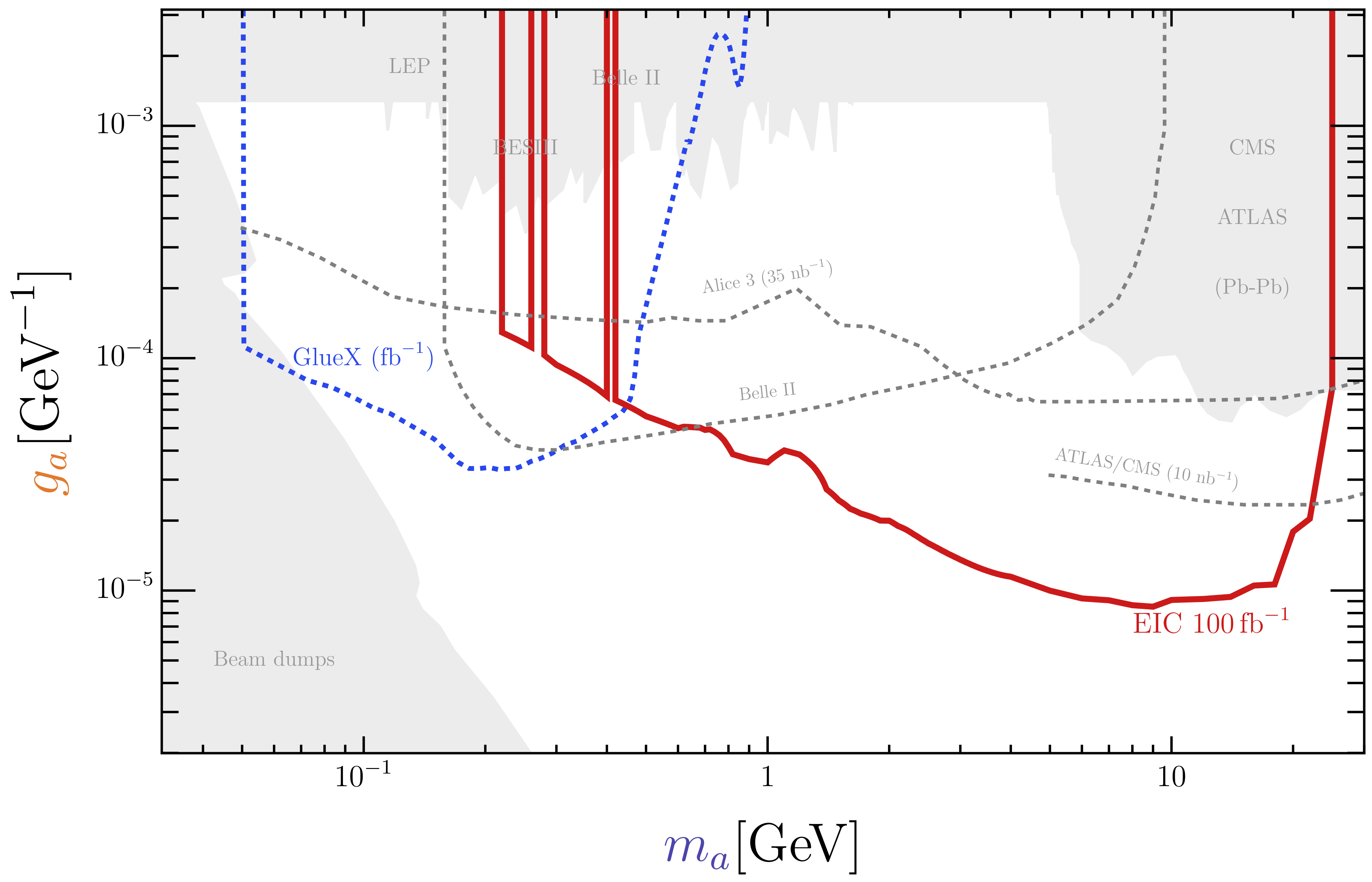

axion is produced and promptly decays to photons

Balkin, Hen, Li, Liu, Ma, YS, Williams JHEP 24

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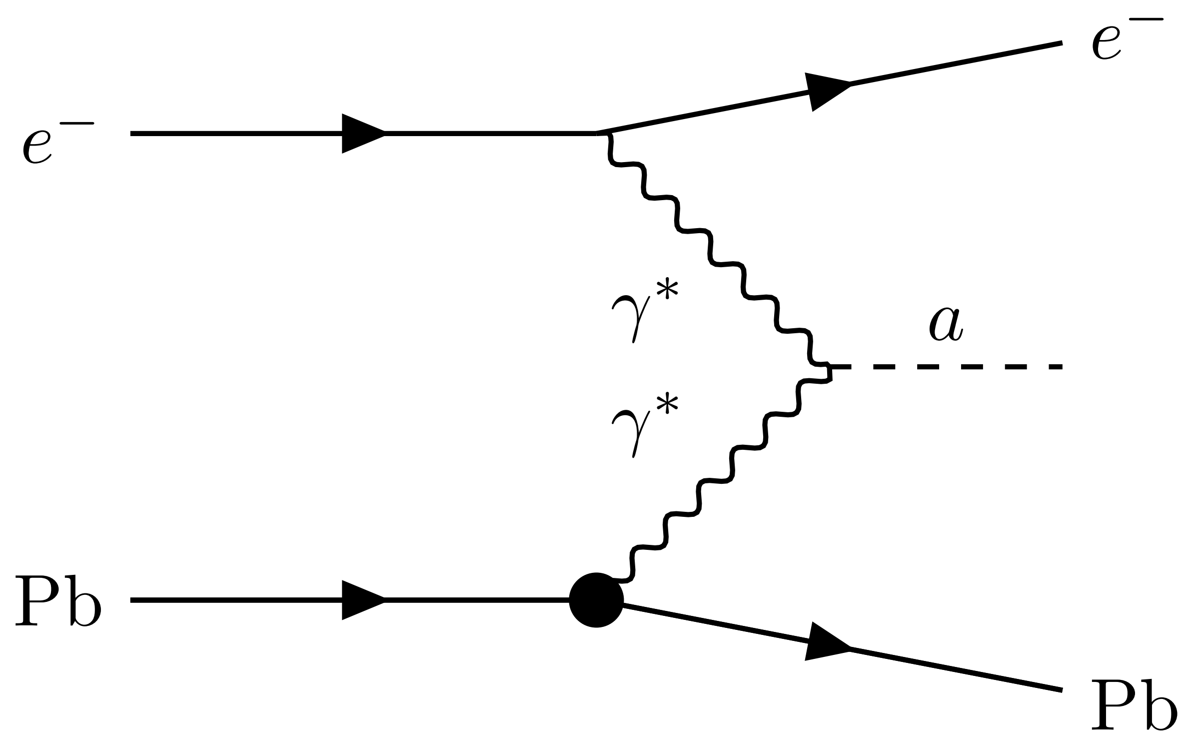
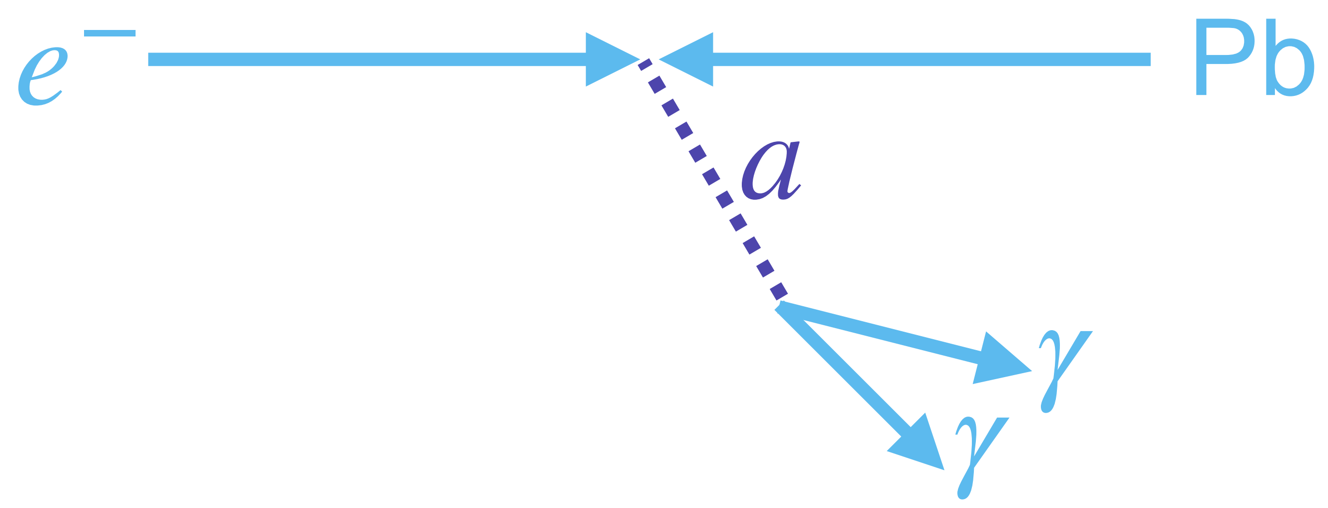
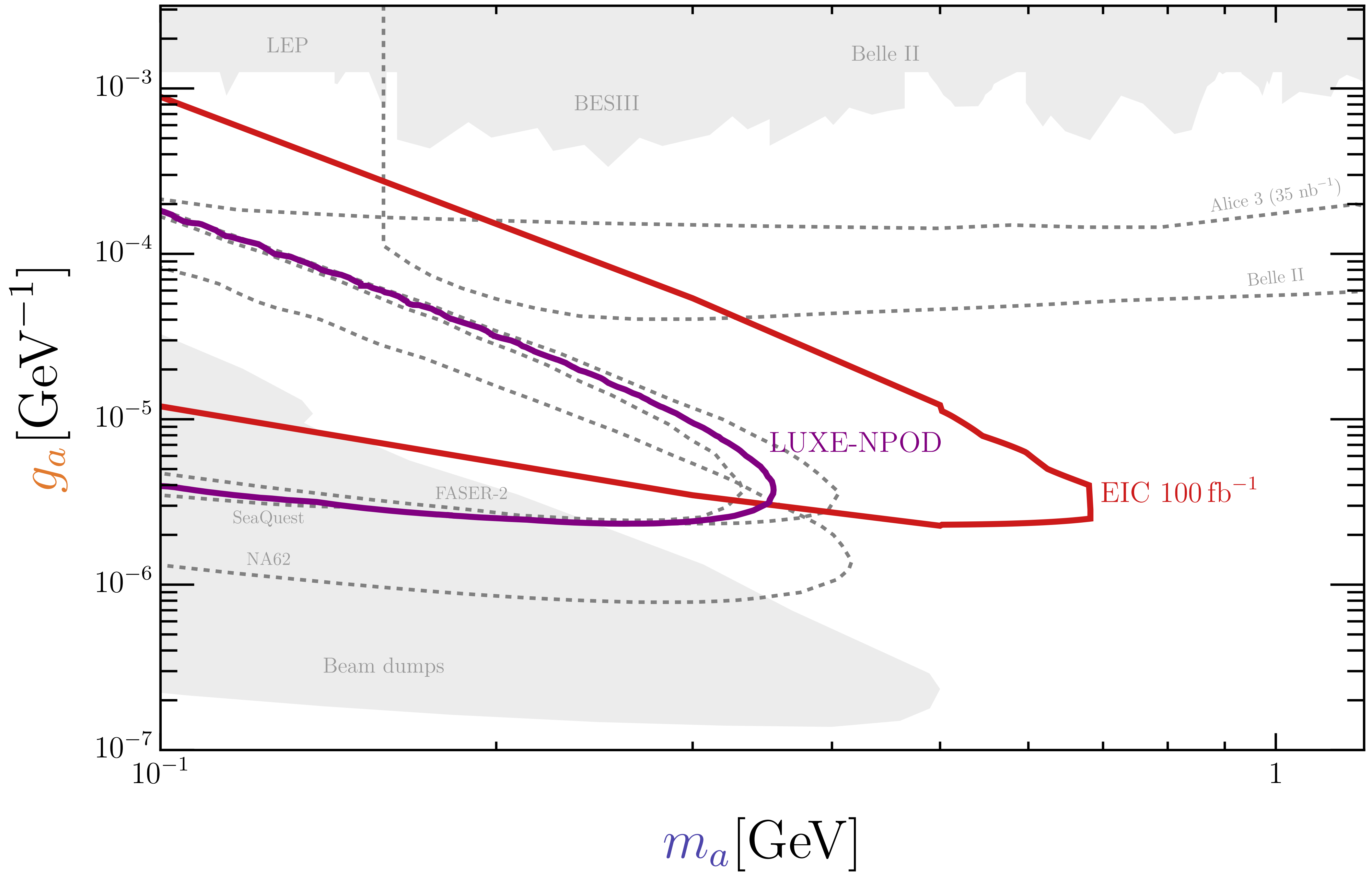


coherent production of new particles up to $m_a \sim 20\,\mathrm{GeV}$

axion is produced, travels a finite distance and decays to photons



displaced



Balkin, Hen, Li, Liu, Ma, YS, Williams JHEP 24

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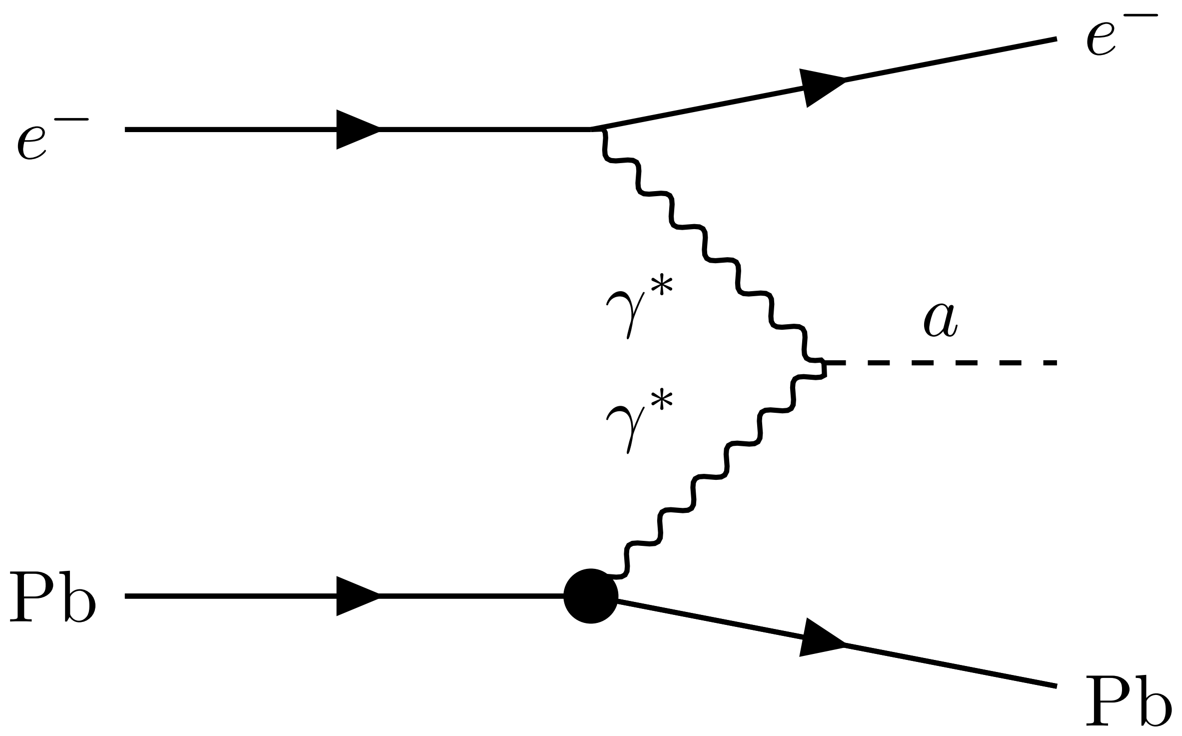
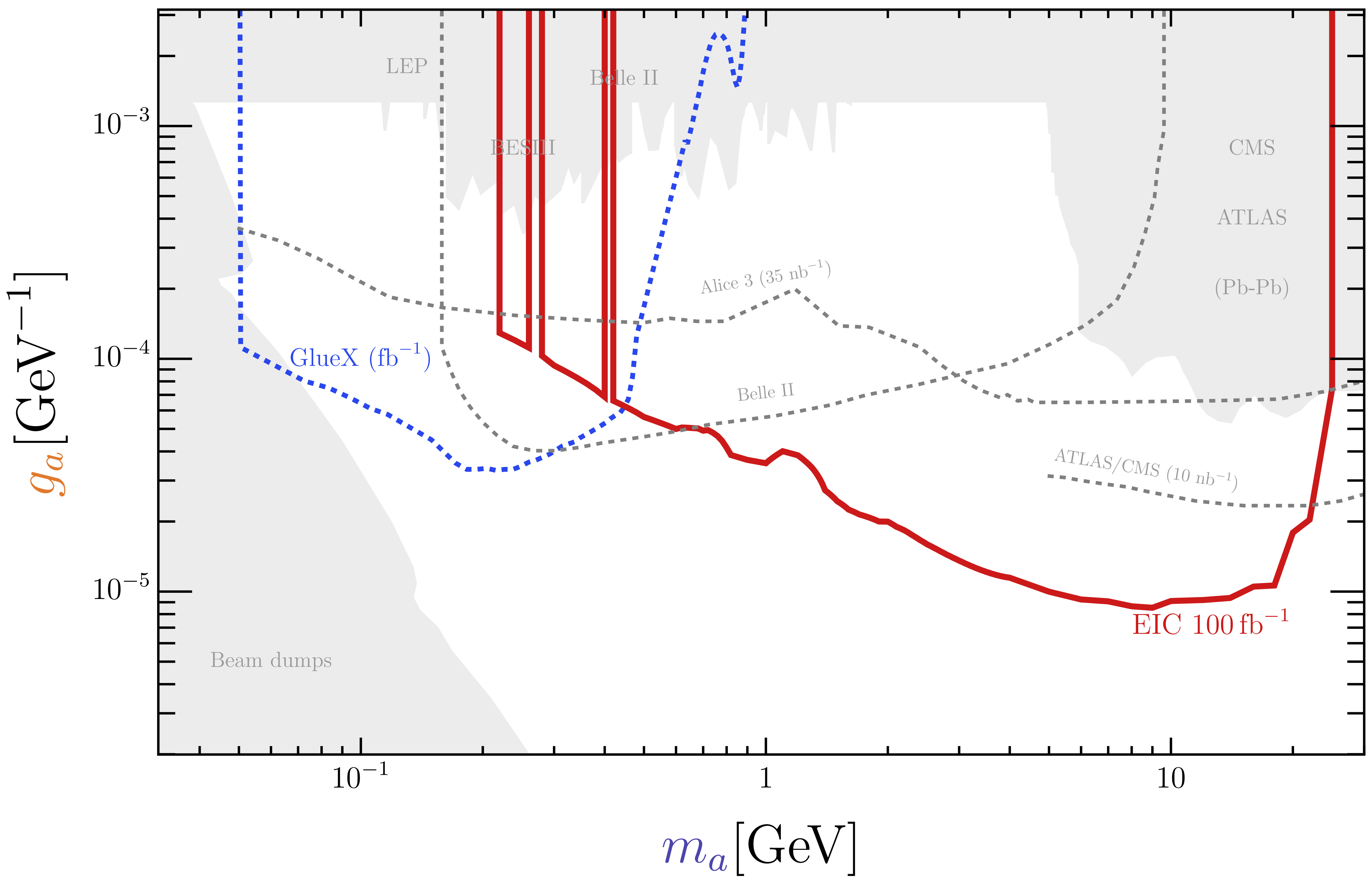


coherent production of new particles up to $m_a \sim 20\,\text{GeV}$

prompt



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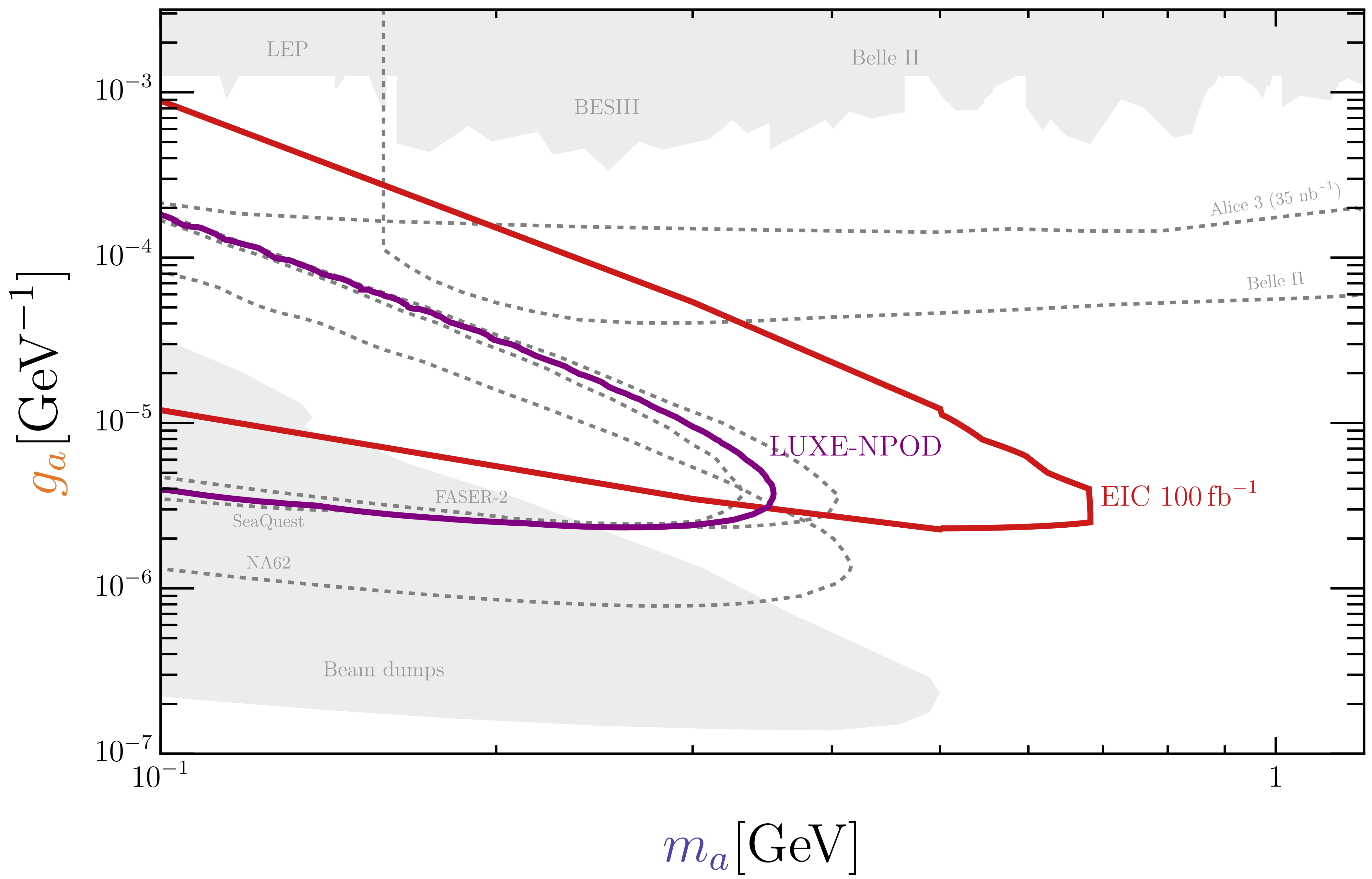
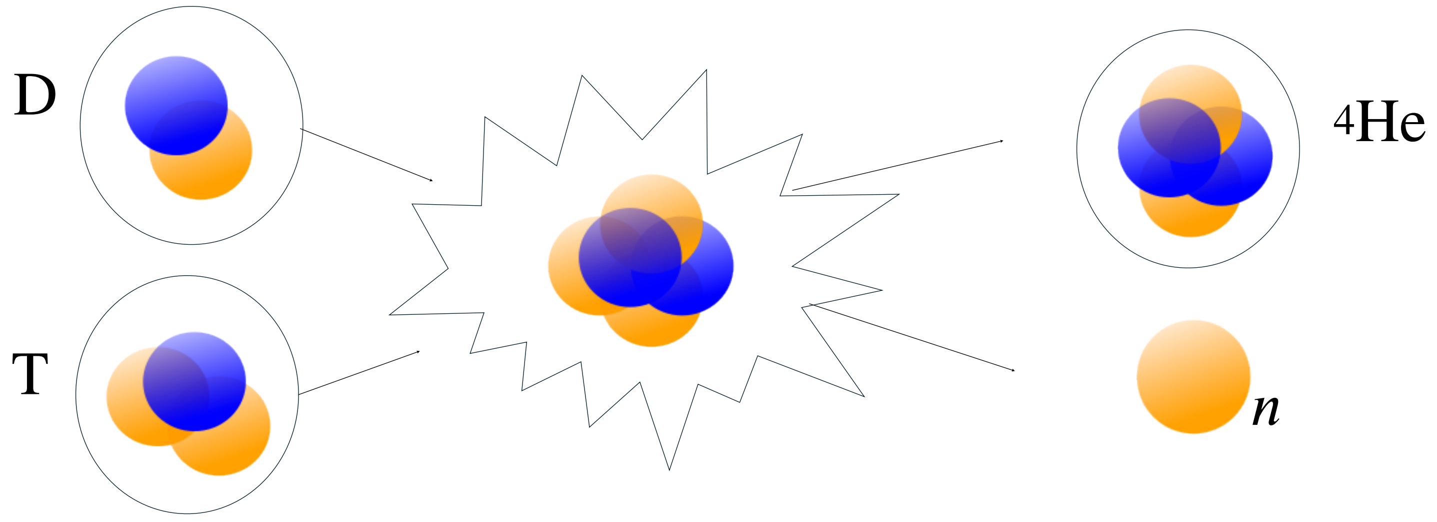


Balkin, Hen, Li, Liu, Ma, YS, Williams JHEP 24

BSM at Fusion reactors

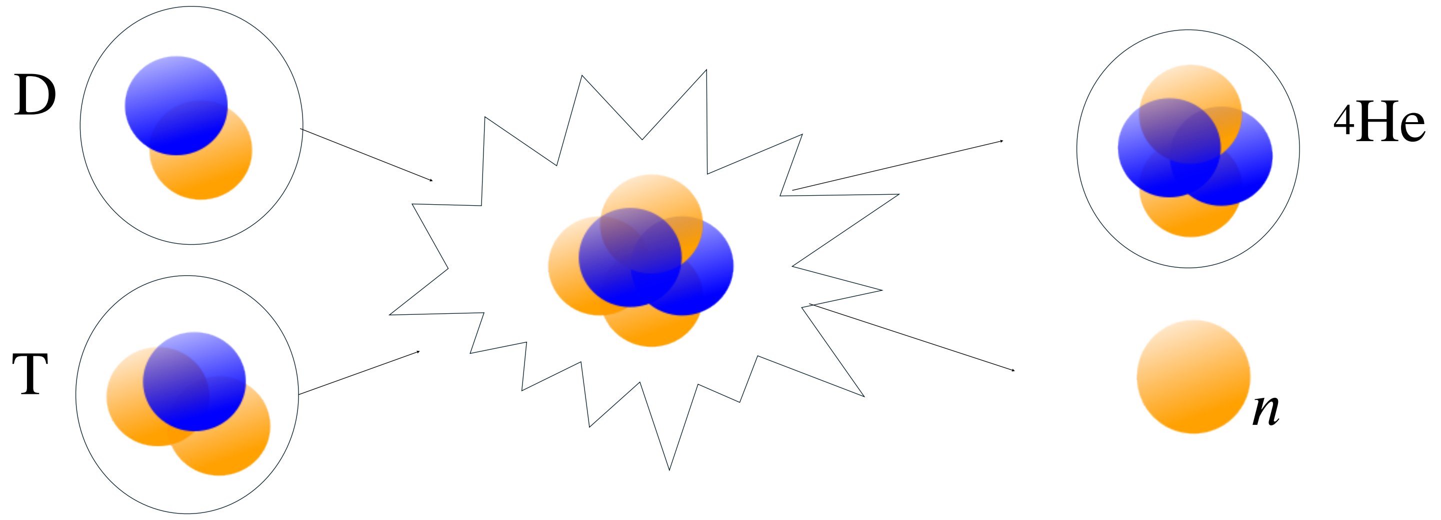


utilize the huge neutron flux

$$\Phi_n^{\rm total} \sim 10^{15} {\rm cm}^{-2} {\rm sec}^{-1}$$

Baruch, Fitzpatrick, Menzo, YS, Trifinopoulos, Zupan, 2502.12314

BSM at Fusion reactors



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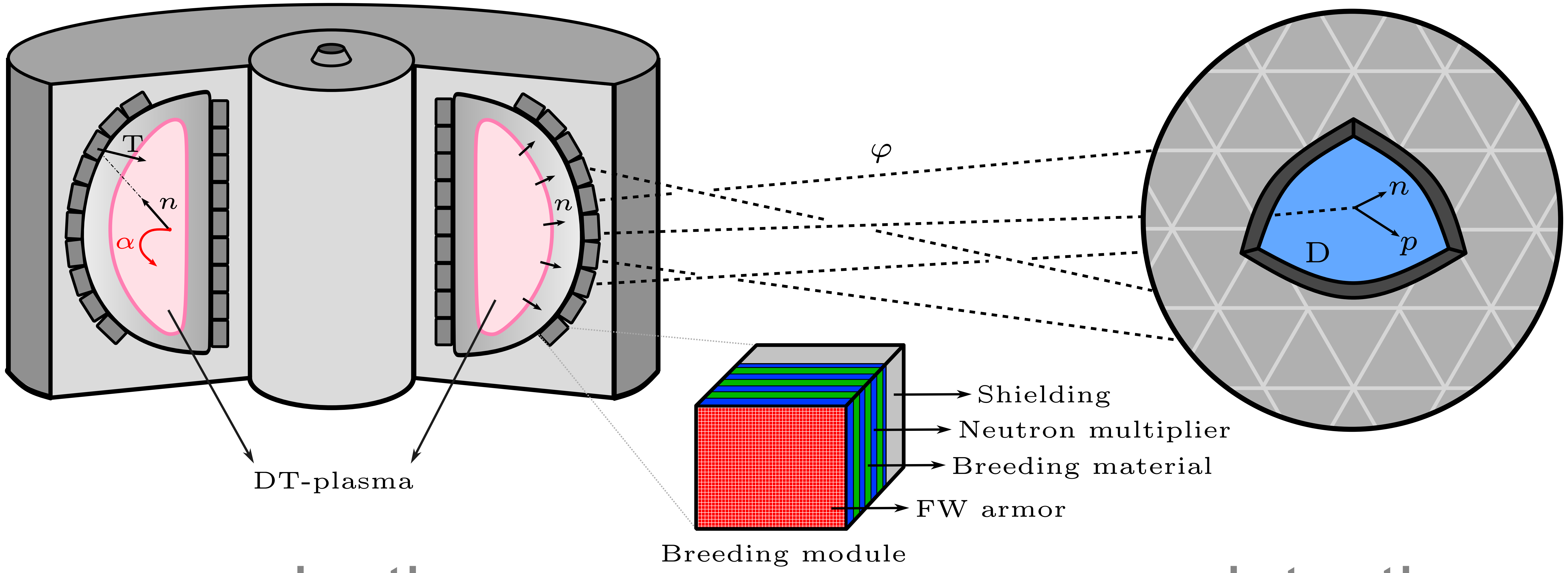

production

detection

Baruch, Fitzpatrick, Menzo, YS, Trifinopoulos, Zupan, 2502.12314

New physics production

utilize the huge neutron flux
+ blanket as a target

Baruch, Fitzpatrick, Menzo, YS, Trifinopoulos, Zupan, 2502.12314

New physics production

utilize the huge neutron flux
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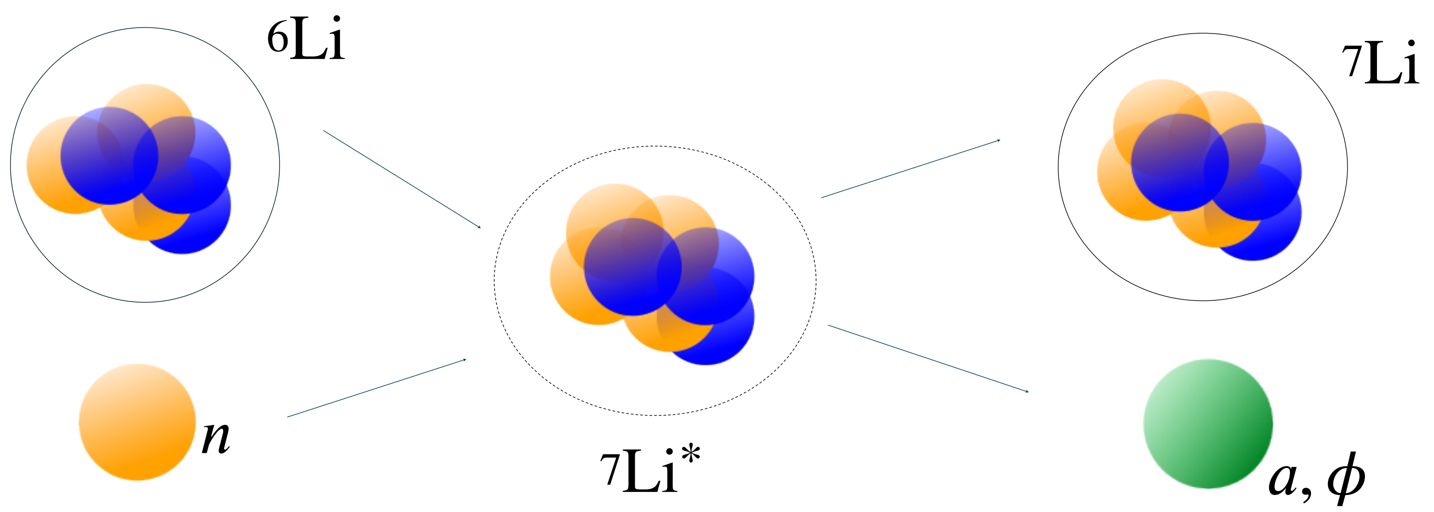

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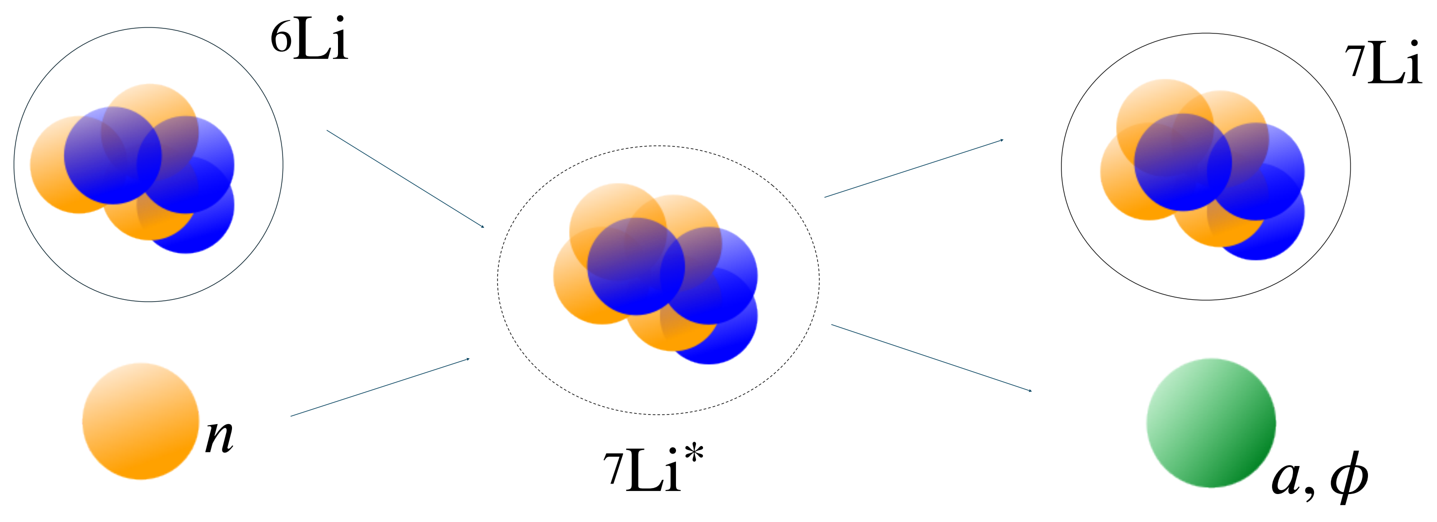
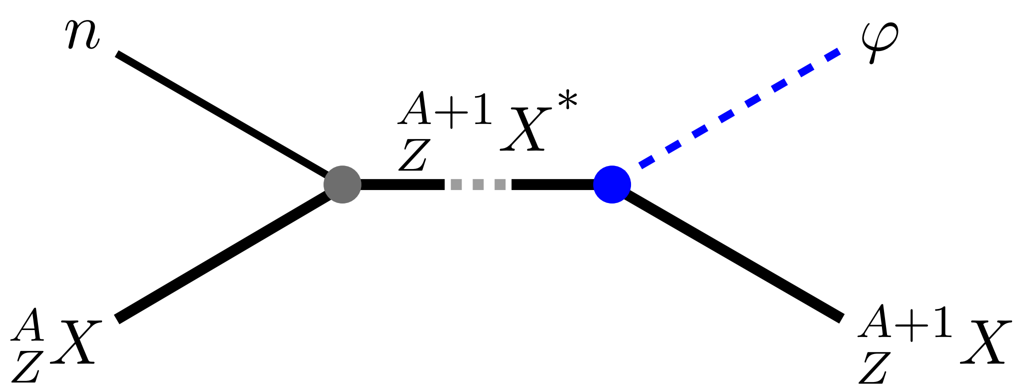




Resonant capture + de-excitation

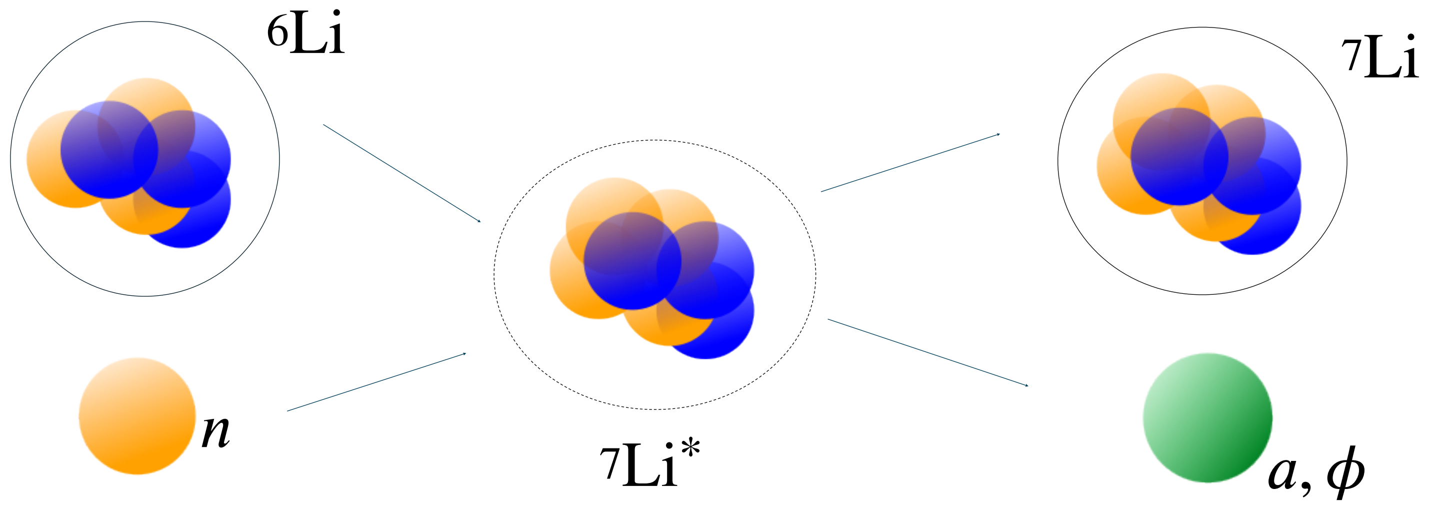
$$n + {}^{A}_{Z}X \to {}^{A+1}_{Z}X* \to {}^{A+1}_{Z}X + \varphi$$

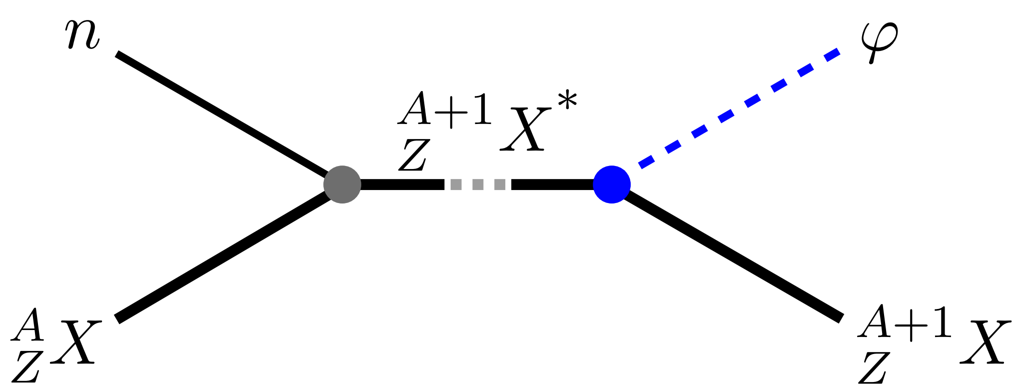
$$\frac{\sigma_{a;\mathrm{M1}}}{\sigma_{\gamma;\mathrm{M1}}} \propto \left(\frac{p_a}{E_\gamma}\right)^3 \frac{g_{ap}^2}{2\pi\alpha}, \frac{\sigma_{\phi;\mathrm{M1}}}{\sigma_{\gamma;\mathrm{M1}}} \propto \frac{p_\phi}{E_\gamma} \frac{g_{\phi p}^2}{2\pi\alpha}$$

Baruch, Fitzpatrick, Menzo, YS, Trifinopoulos, Zupan, 2502.12314

New physics production

utilize the huge neutron flux
+ blanket as a target

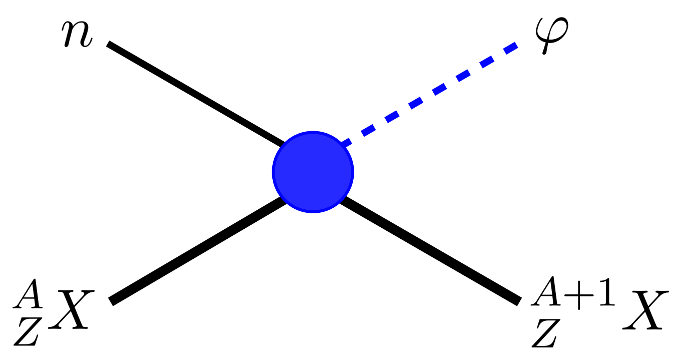




Resonant capture + de-excitation

$$n + {}^A_Z X \to {}^{A+1}_Z X^* \to {}^{A+1}_Z X + \varphi$$

$$\frac{\sigma_{a;\mathrm{M1}}}{\sigma_{\gamma;\mathrm{M1}}} \propto \left(\frac{p_a}{E_\gamma}\right)^3 \frac{g_{ap}^2}{2\pi\alpha}, \quad \frac{\sigma_{\phi;\mathrm{M1}}}{\sigma_{\gamma;\mathrm{M1}}} \propto \frac{p_\phi}{E_\gamma}\frac{g_{\phi p}^2}{2\pi\alpha}$$



Non-resonant capture + de-excitation

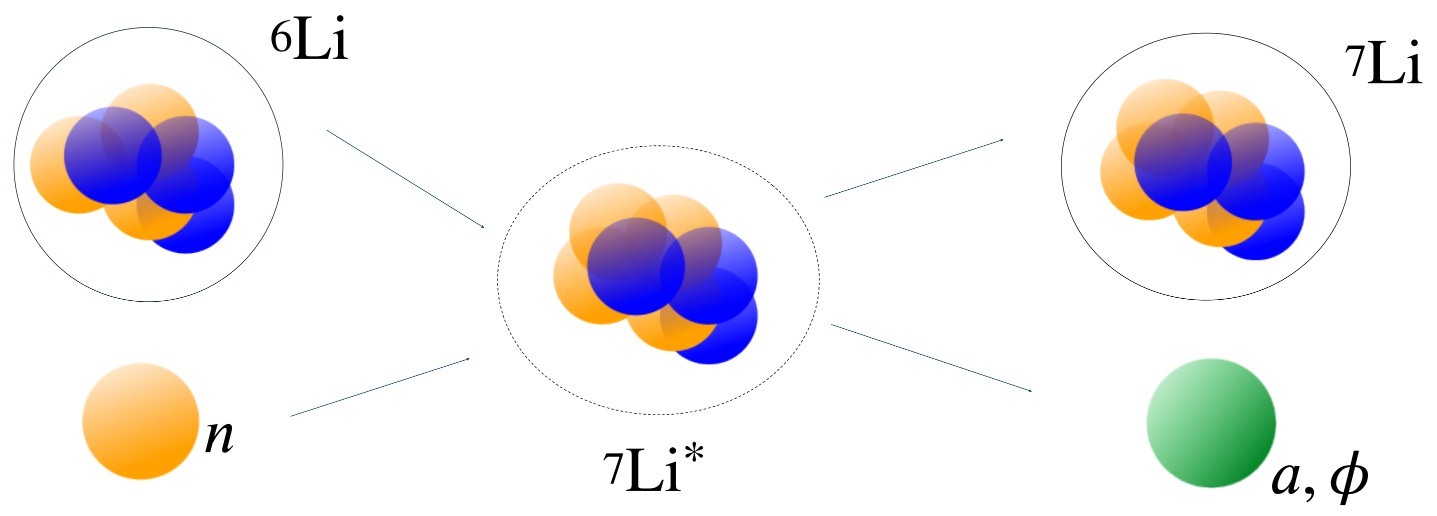
$$n + {}^A_Z X \to {}^{A+1}_Z X + \varphi$$

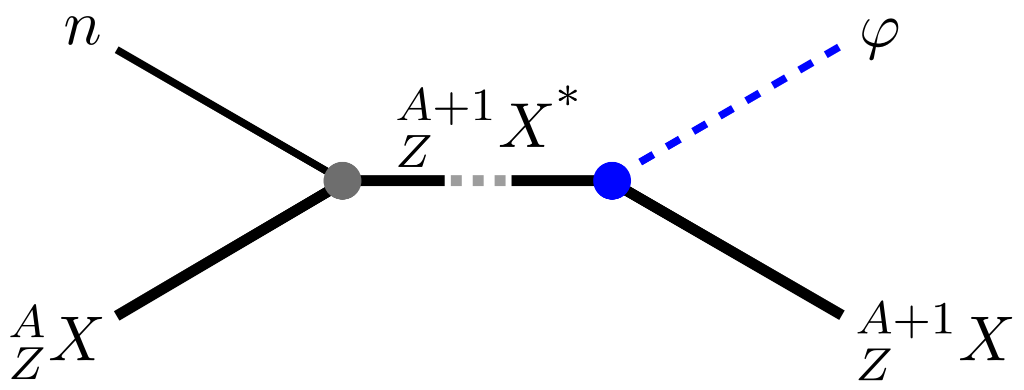
$$\frac{\sigma_\phi^{\mathrm{non-res}}}{\sigma_{\gamma;\mathrm{E1}}^{\mathrm{non-res}}} \sim \frac{g_{\phi p}^2}{e^2}\frac{Q^2}{E_\gamma^2}\frac{p_\phi}{E_\gamma}$$

Baruch, Fitzpatrick, Menzo, YS, Trifinopoulos, Zupan, 2502.12314

New physics production

utilize the huge neutron flux
+ blanket as a target





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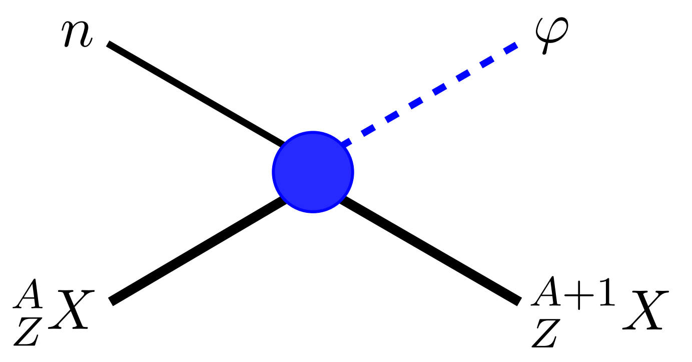

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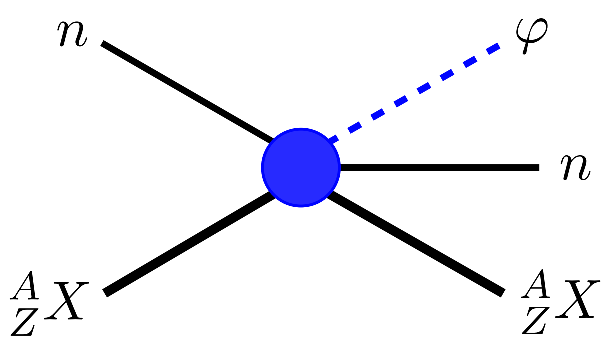

Coherent scattering

$$n + {}^{A}_{Z}X \to {}^{A}_{Z}X + n + \varphi$$

$$\frac{\sigma_\phi}{\sigma_{\mathrm{SM}}} \sim \frac{Z^2 g_{\phi p}^2}{16\pi^2 E_\phi^3}\left(E_\phi^2 - m_\phi^2\right)^{3/2}$$

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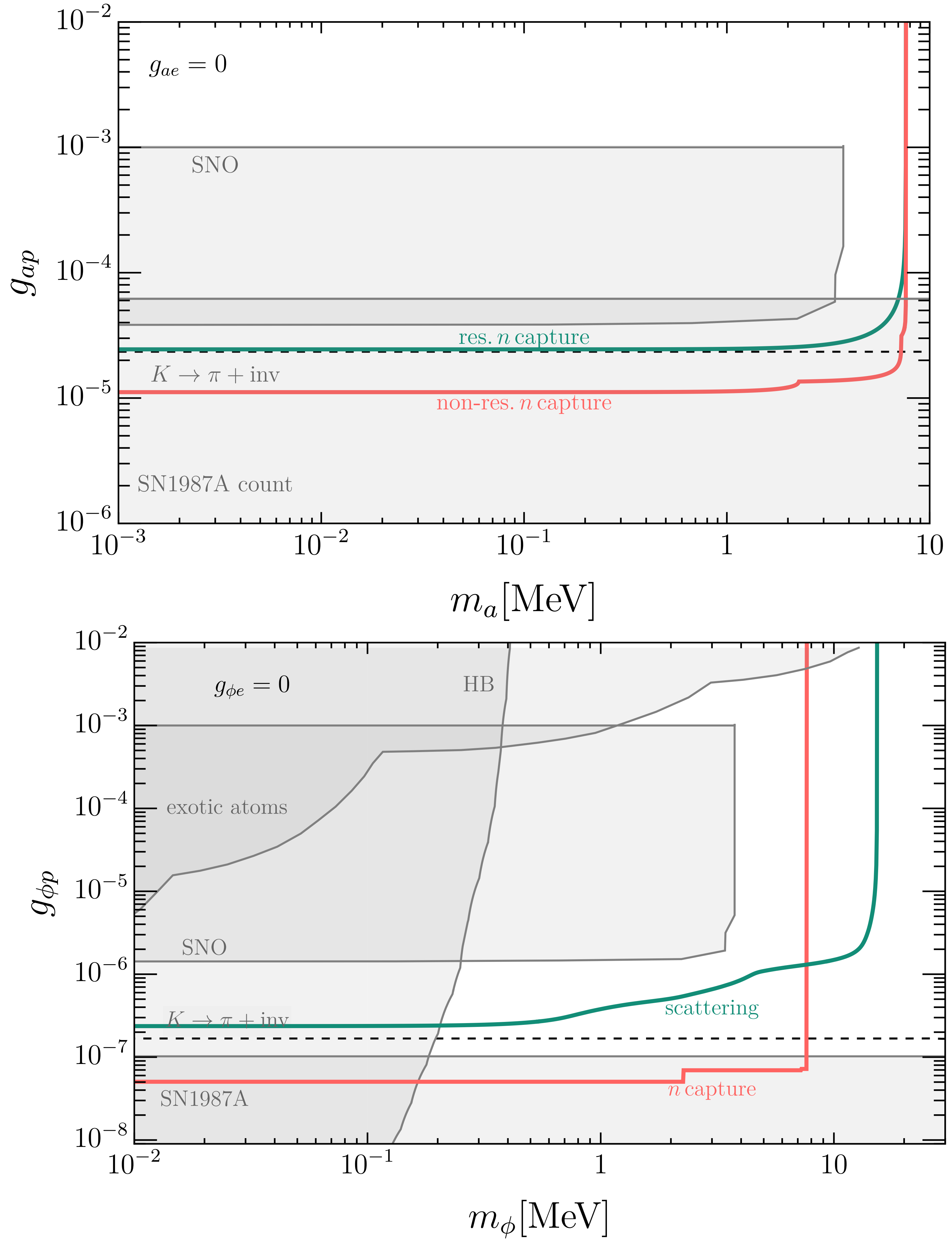
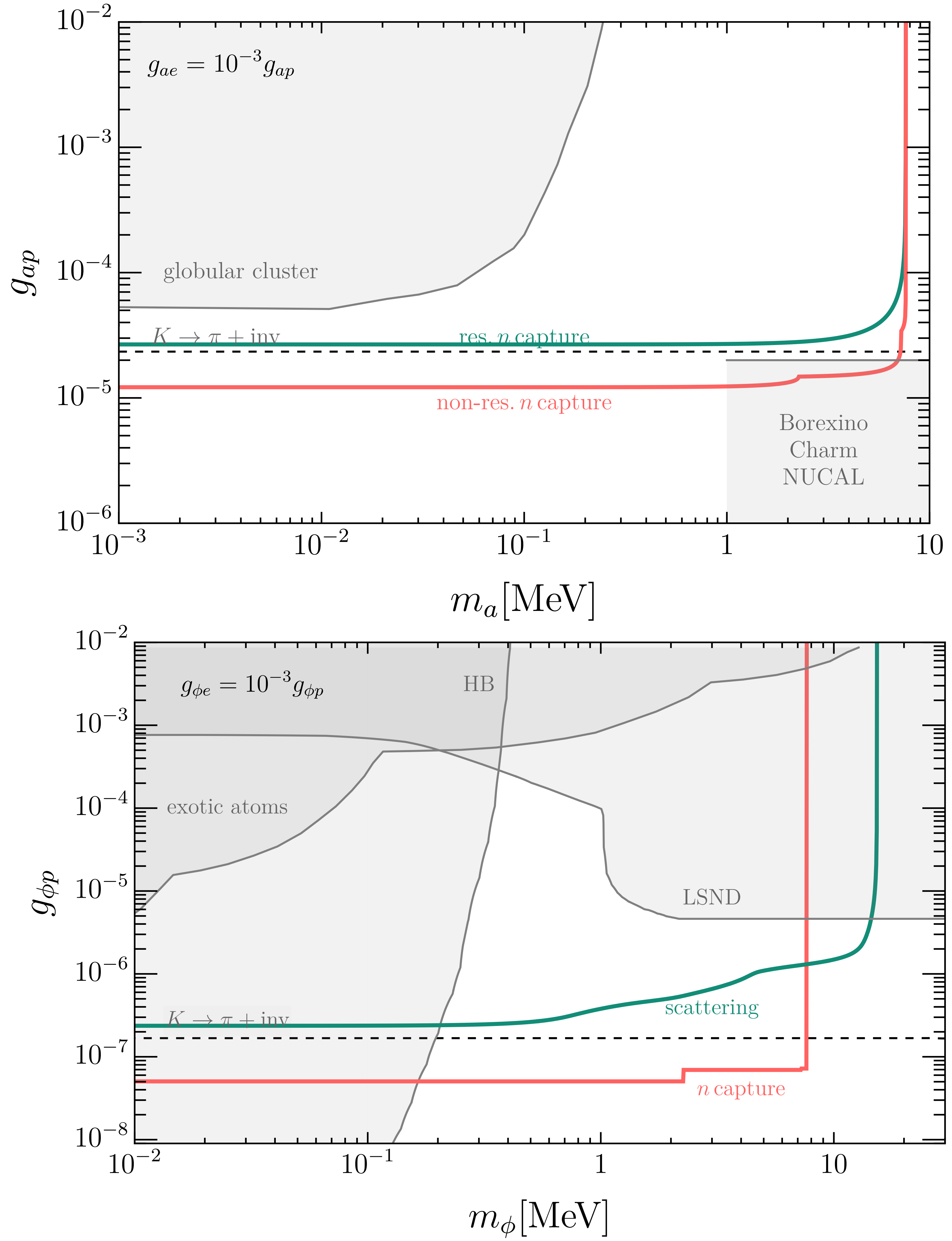
BSM at Fusion reactors

only proton coupling



proton + small electron couplings



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Summary

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- Kaon decay can be disentangled from spectroscopy.

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- Kaon decay can be disentangled from spectroscopy.
- Precision spectroscopy is a powerful probe of new hadronic interactions.
- In the next coming years new options will be open for ALPs physics (LUXE, EIC).

backups

Kaon decays: $K \to \pi\phi$

$$\mathscr{M}(K^+ \to \pi^+\phi) = \frac{1}{f}\left\{ \frac{1}{2}(\kappa_W - K_\Theta)\Big[\gamma_1\big(m_K^2 - m_\phi^2 + m_\pi^2\big) - 2\gamma_2\big(m_K^2 + m_\pi^2\delta_I\big)\Big] + \frac{1}{4}\kappa_{sd}^{\phi*}\,\big[2m_K^2 - m_\pi^2(1-\delta_I)\big] + \frac{m_\pi^2}{4}\kappa_{ds}^{\phi*}(1+\delta_I) \right.$$
$$\left. -\frac{m_\pi^2}{4}\left(\kappa_u^\phi - \frac{\kappa_{s+d}^\phi}{2}\right)\gamma_1(1-\delta_I) + \frac{m_\pi^2\kappa_{s-d}^\phi}{8(m_K^2 - m_\pi^2)}\Big(m_K^2\big[(3+\delta_I)\gamma_1 - 4(1+\delta_I)\gamma_2\big] - m_\pi^2\big[(1-\delta_I)\gamma_1 - 2\gamma_2\big]\Big) \right\}$$

$$\mathscr{M}(K_L \to \pi^0\phi) = -\frac{1}{f}\left\{ \frac{1}{2}(\kappa_W - K_\Theta)\Big[\gamma_1\big(m_K^2 - m_\phi^2 + m_\pi^2\big) - 2\gamma_2 m_K^2\Big] + \frac{1}{4}\text{Re}\,\kappa_{sd}^\phi\,\big[2m_K^2 - m_\pi^2(1+\delta_I)\big] \right.$$
$$\left. +\frac{m_\pi^2}{4}\text{Re}\,\kappa_{ds}^\phi(1+\delta_I) + \frac{\kappa_{s-d}^\phi m_\pi^2}{4(m_K^2 - m_\pi^2)}(\gamma_1 - \gamma_2)\big[2m_K^2(1+\tilde{\delta}_I) - m_\pi^2\big] \right\}$$

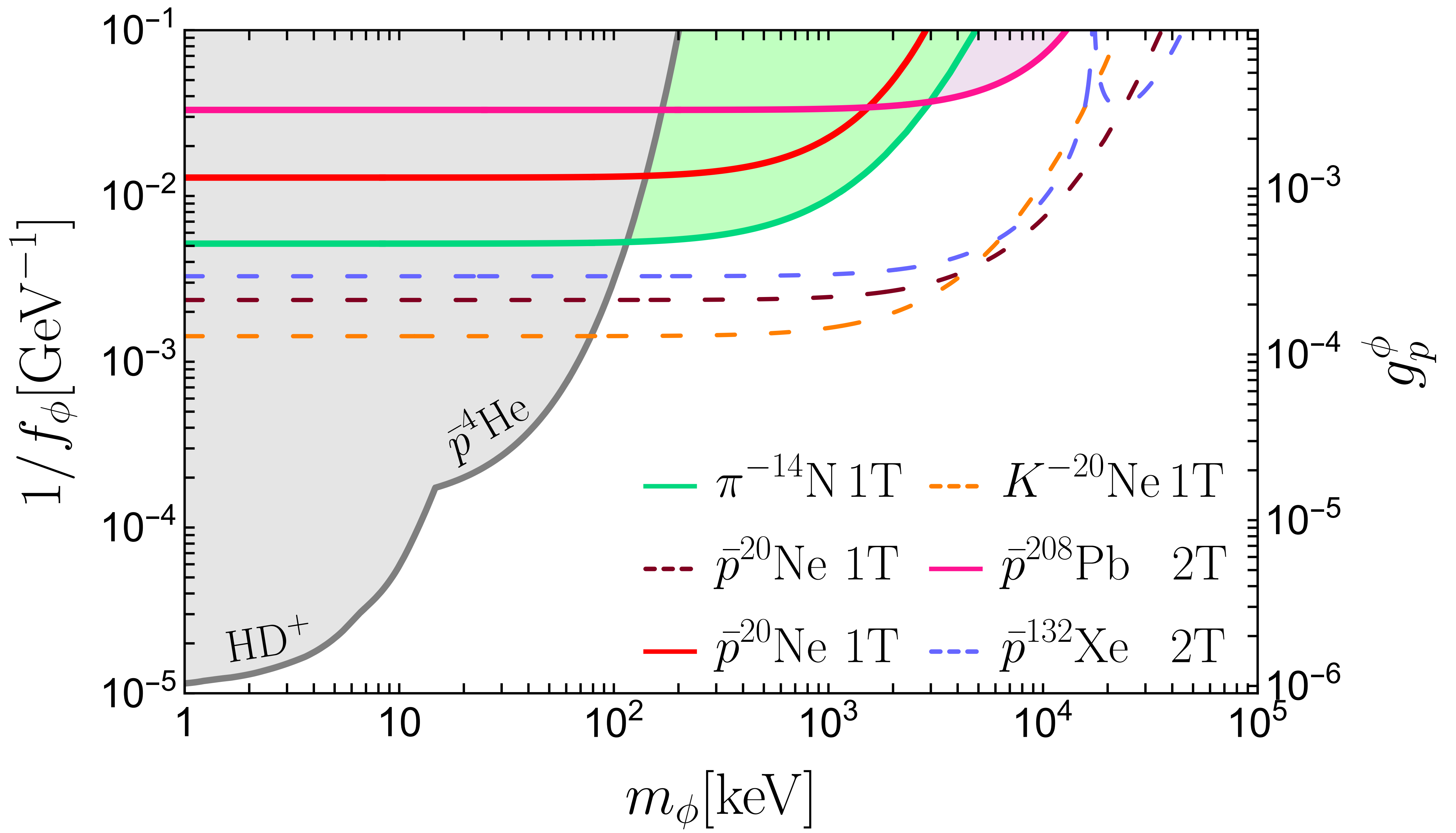
$$\mathscr{M}(K_S \to \pi_{\text{int}}^0\phi) = \frac{1}{4f}\left\{ \text{Im}\,\kappa_{sd}^\phi\,\big[2m_K^2 - m_\pi^2(1+\delta_I)\big] + \text{Im}\,\kappa_{ds}^\phi m_\pi^2(1+\delta_I) \right\}$$

$$\mathscr{M}(K^+ \to \pi^+\phi) + \mathscr{M}(K_L \to \pi^0\phi) + i\mathscr{M}(K_S \to \pi^0\phi) = 0$$

Delaunay, Kitahara, YS, Zupan, 2501.16477

Exotic atoms for BSM

uds-model

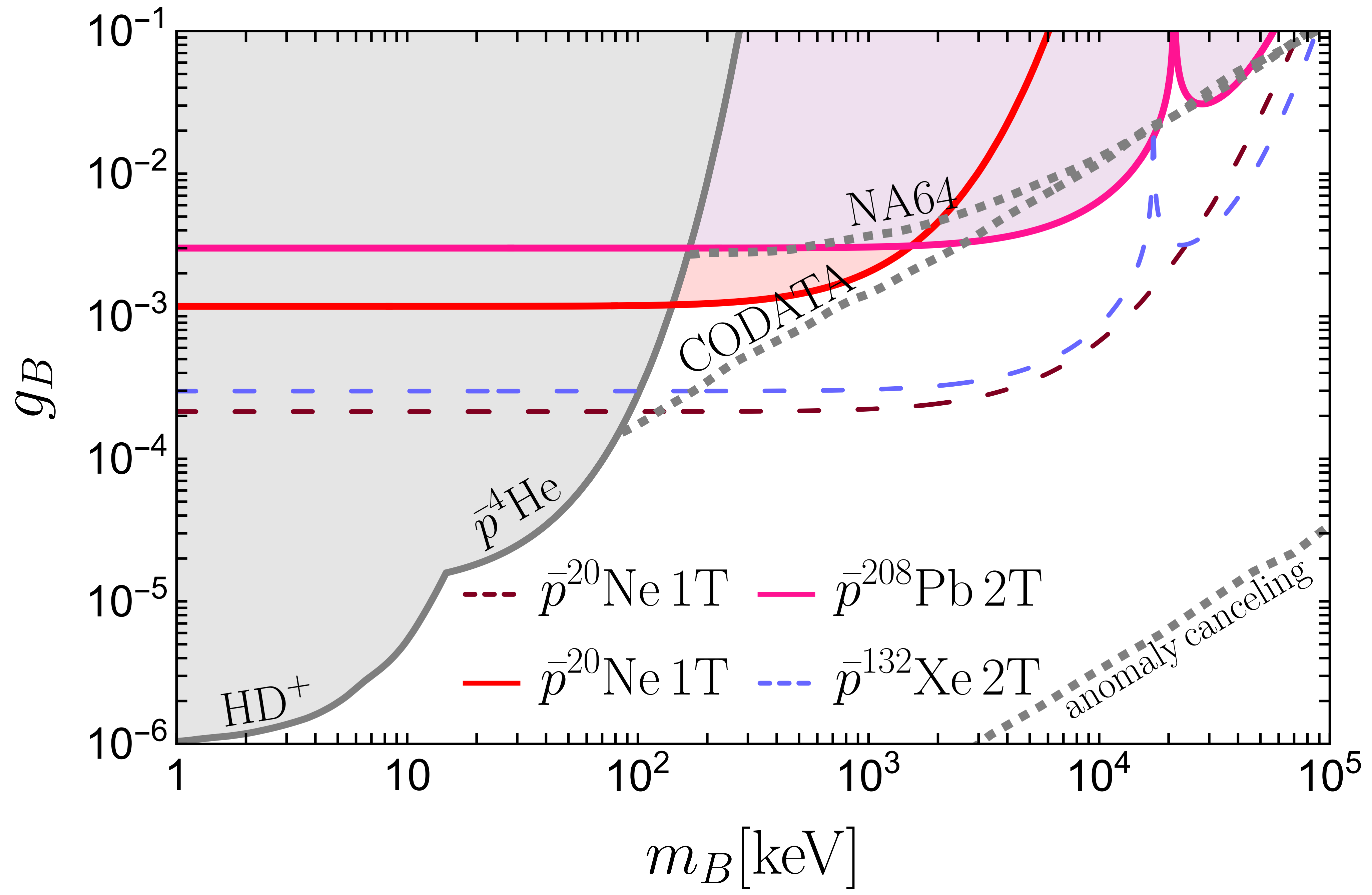


$$\frac{\phi}{f_\phi}\sum_{q=u,d,s} m_q \bar{q} q$$

avoid bounds from $K \to \pi + \mathrm{inv}$

Delaunay, Kitahara, YS, Zupan, 2501.16477

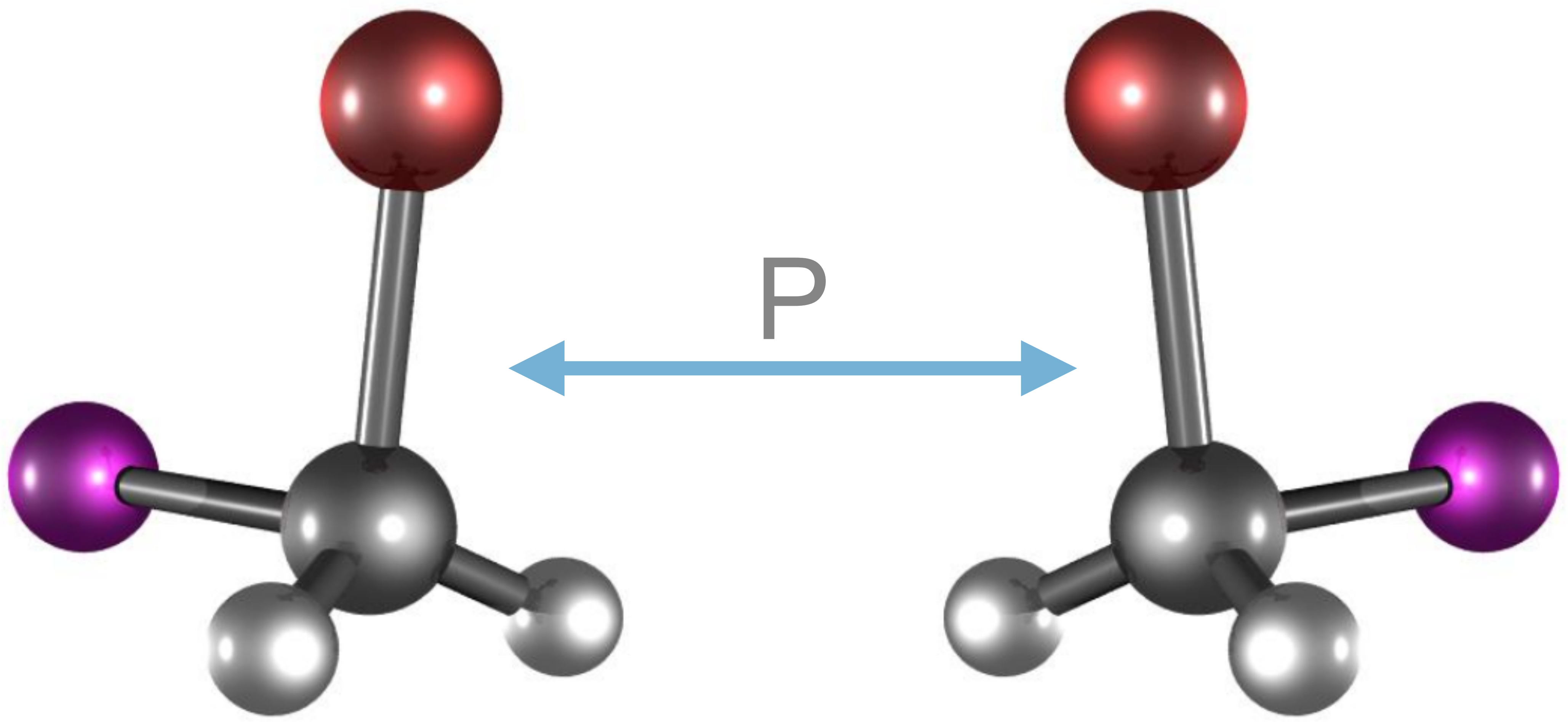
B-number + invisible



$$\frac{g_B}{3}B^\mu \sum_q \bar{q}\gamma_\mu q - \frac{g_B e^2}{48\pi^2}B^\mu \sum_\ell \bar{\ell}\gamma_\mu \ell$$

Liu, Ohayon, Shtaif, YS, 2502.03537

P violation in chiral molecules



$E_L \neq E_R \Rightarrow$ parity violation

within the SM tiny effect (weak interaction)

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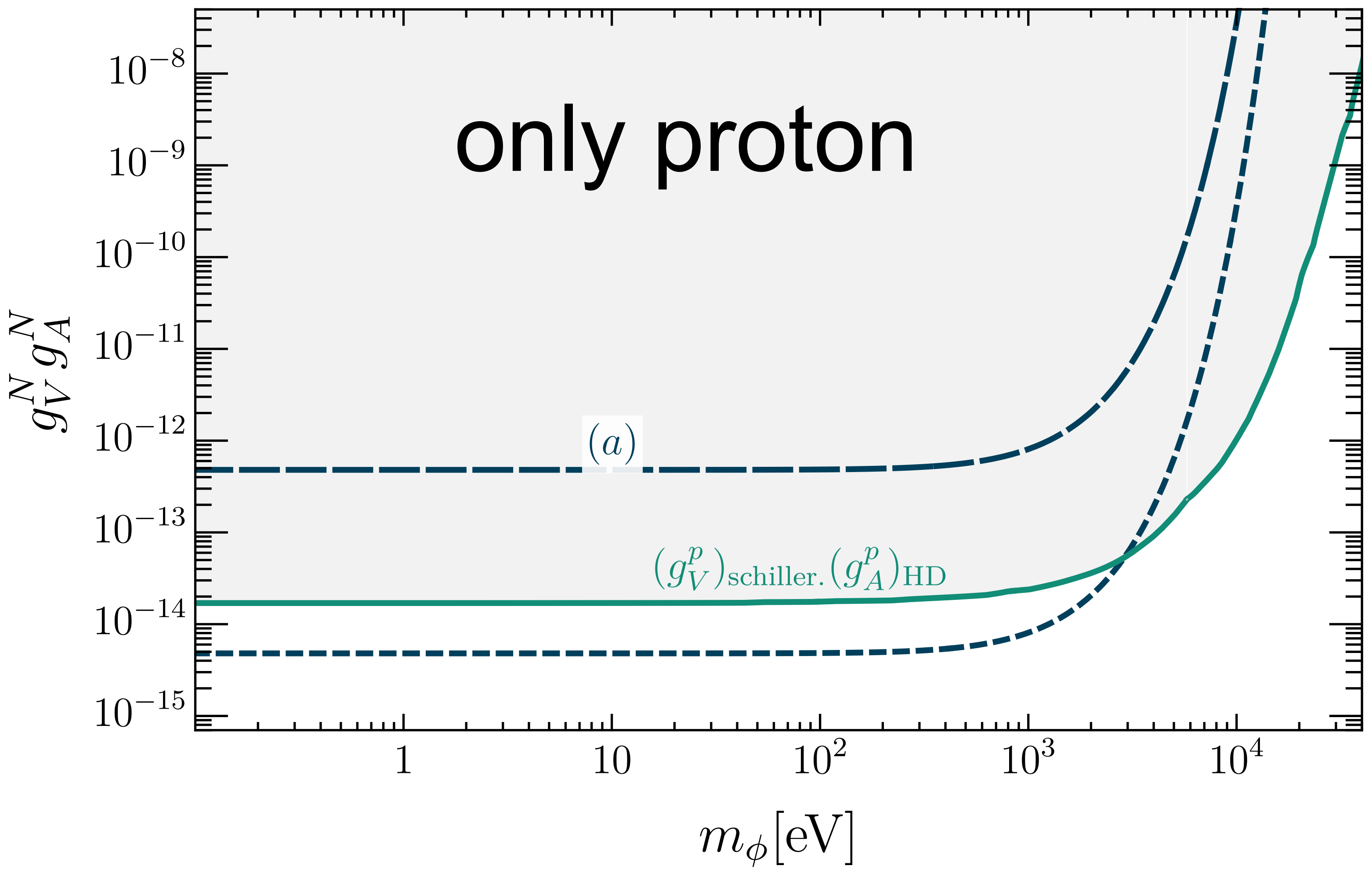
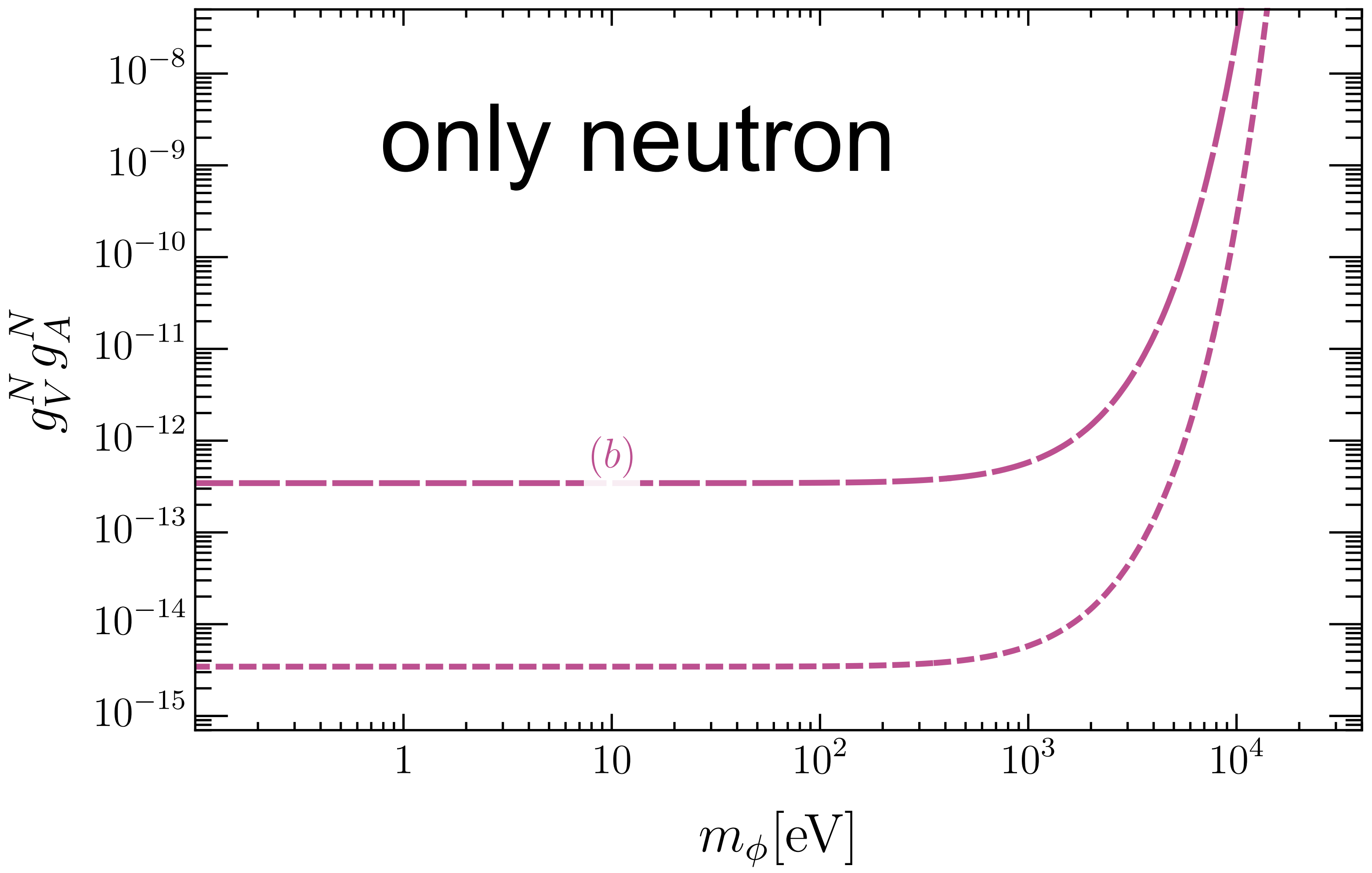
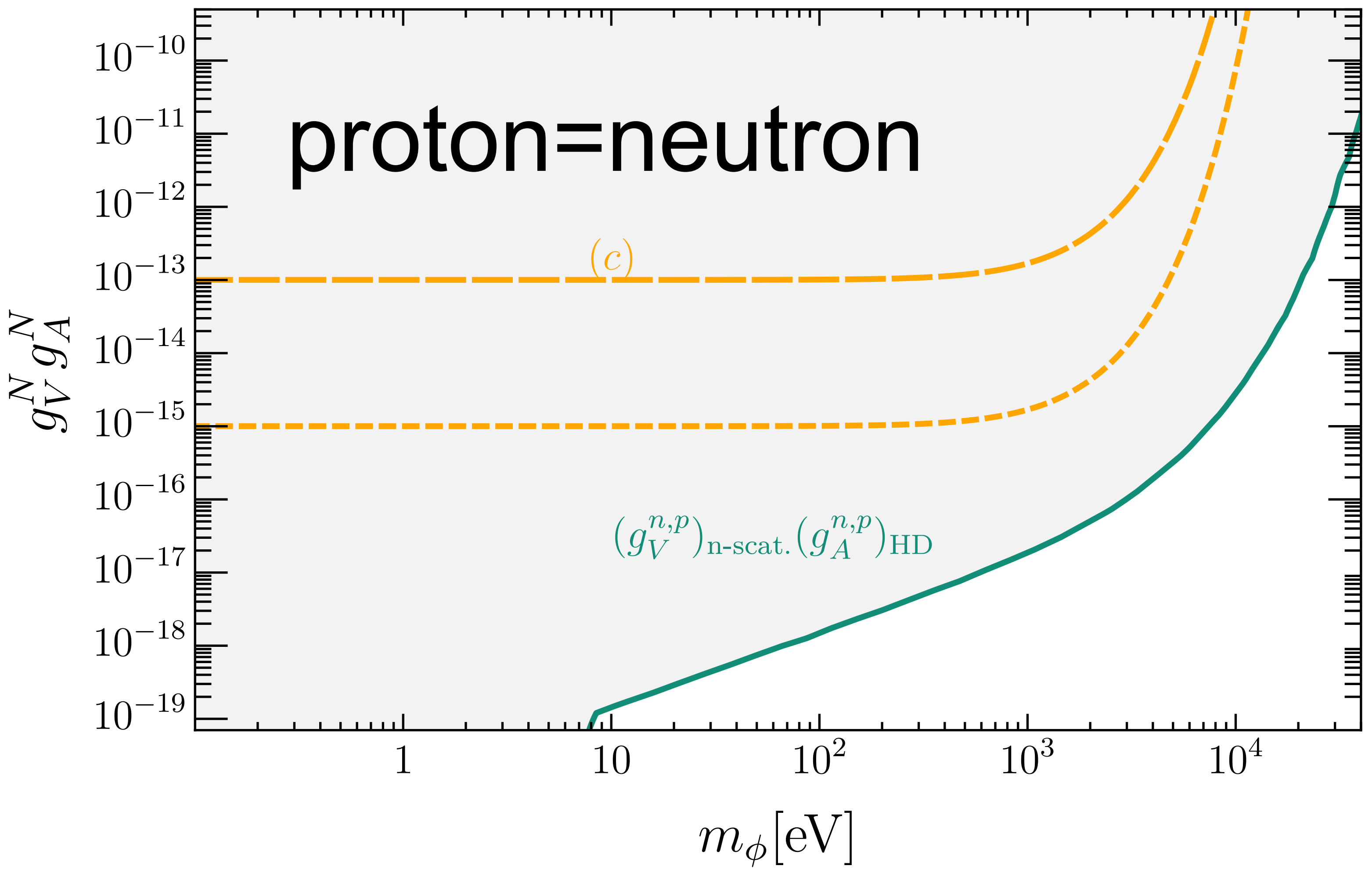
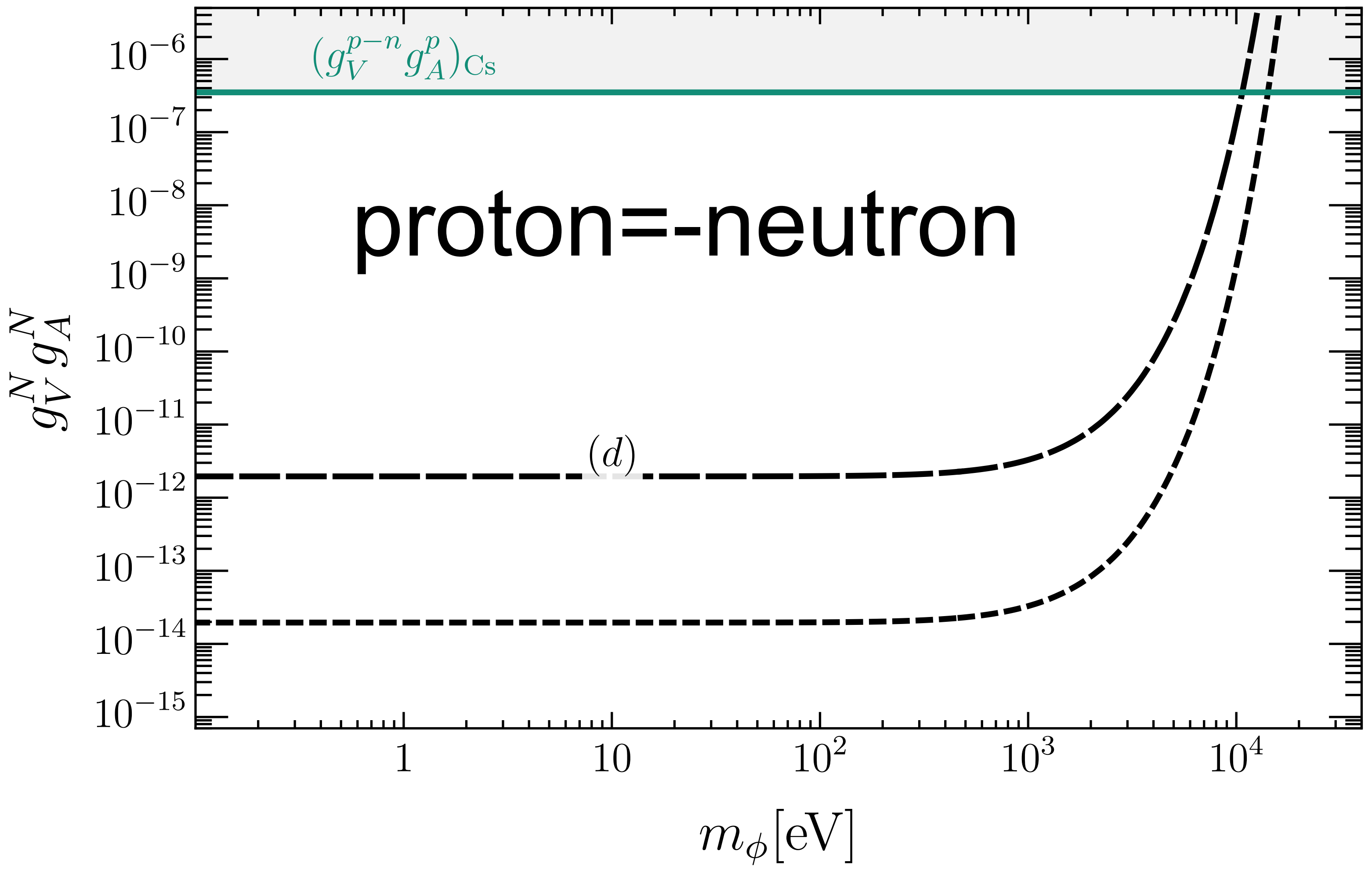
P violation in chiral molecules

comparing the hyperfine structure of L and R









CHDBrI⁺ (Shagam lab)

			state 1		state 2	
	(i,j)	$E_{1\to 2}$ [GHz]	$\langle N,K_a,K_c,J,F_1,F_2,F_3,F\vert$	$\langle\sigma_i\times\sigma_j\rangle\cdot\hat{r}^{ij}_{\rm eq}$	$\vert N,K_a,K_c,J,F_1,F_2,F_3,F\rangle$	$\langle\sigma_i\times\sigma_j\rangle\cdot\hat{r}^{ij}_{\rm eq}$
(a),(b),(c)	(D, I)	3.34	$\langle 1,1,0,\frac{3}{2},1,1,\frac{5}{2},0\vert$	0.49	$\vert 1,0,1,\frac{1}{2},1,2,\frac{7}{2},1\rangle$	0.12
(d)	(H, I)	3.99	$\langle 2,2,0,\frac{5}{2},3,3,\frac{5}{2},0\vert$	0.23	$\vert 1,0,1,\frac{3}{2},1,2,\frac{3}{2},1\rangle$	0

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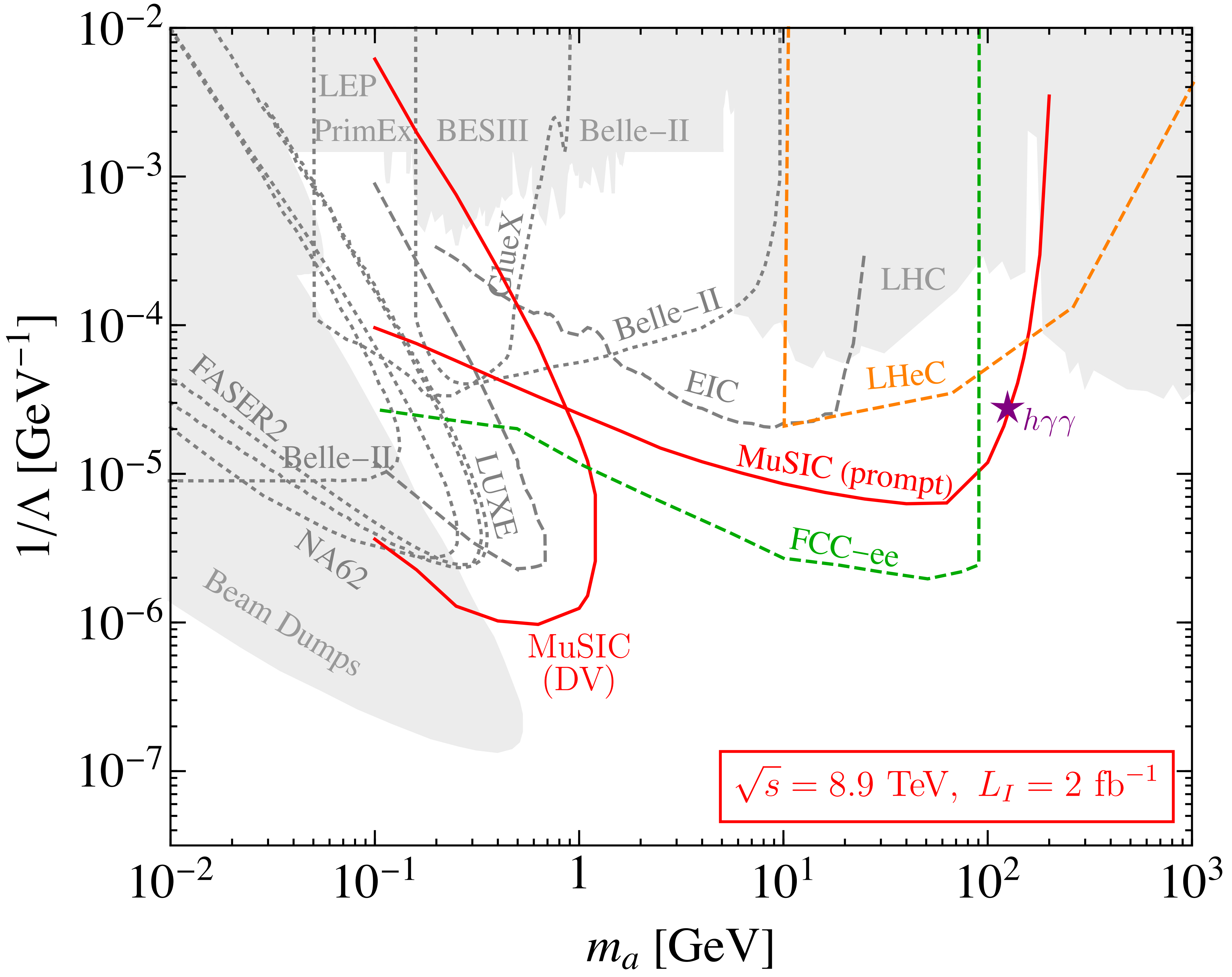
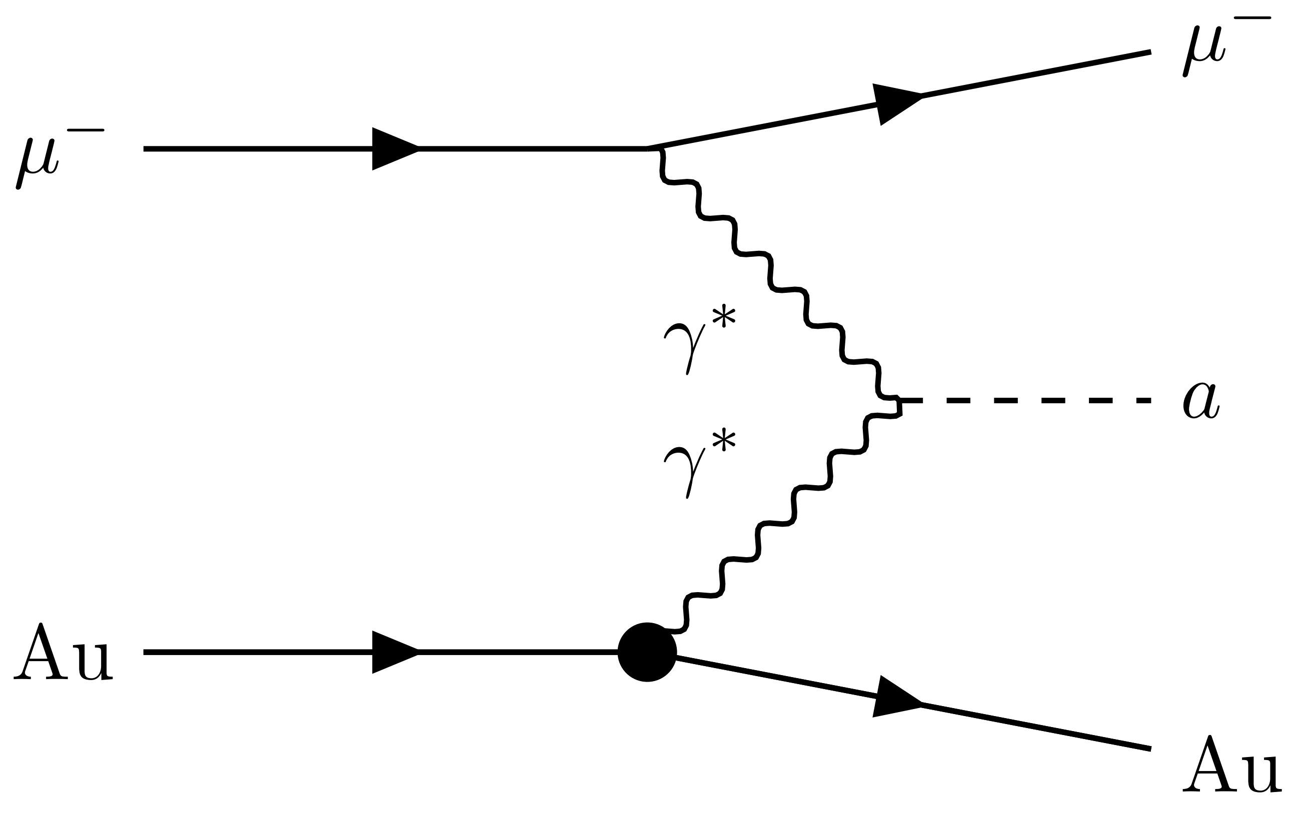
Axions at muon-ion collider (MuSIC)

How can we go more further (next decades)?
muon-ion collider

Davoudiasl, Liu, Marcarelli, YS, Trifinopoilos 2412.13289

Axions at muon-ion collider (MuSIC)





coherent production of new particles up to $m_a \sim 200\,\mathrm{GeV}$

$E_\mu \approx 1\,\mathrm{TeV}, E_{\mathrm{Au}} \approx 20\,\mathrm{TeV}$

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BSM at Fusion reactors

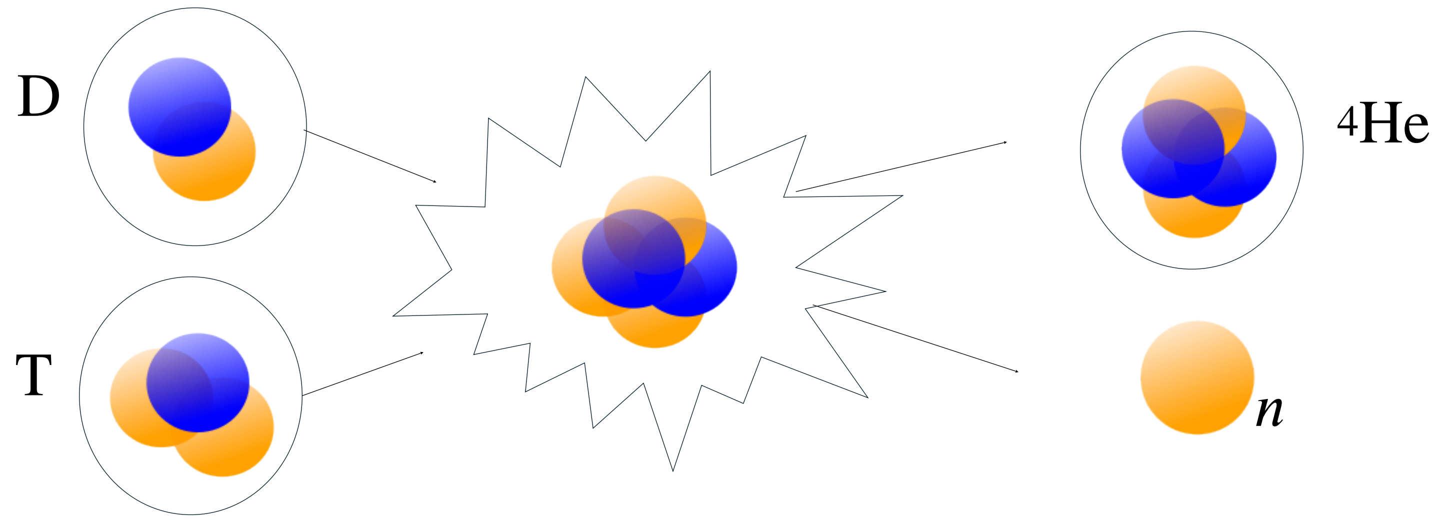
$$^2_1\text{D} + ^3_1\text{T} \rightarrow ^4_2\text{He} + n + 17.6\,\text{MeV}$$

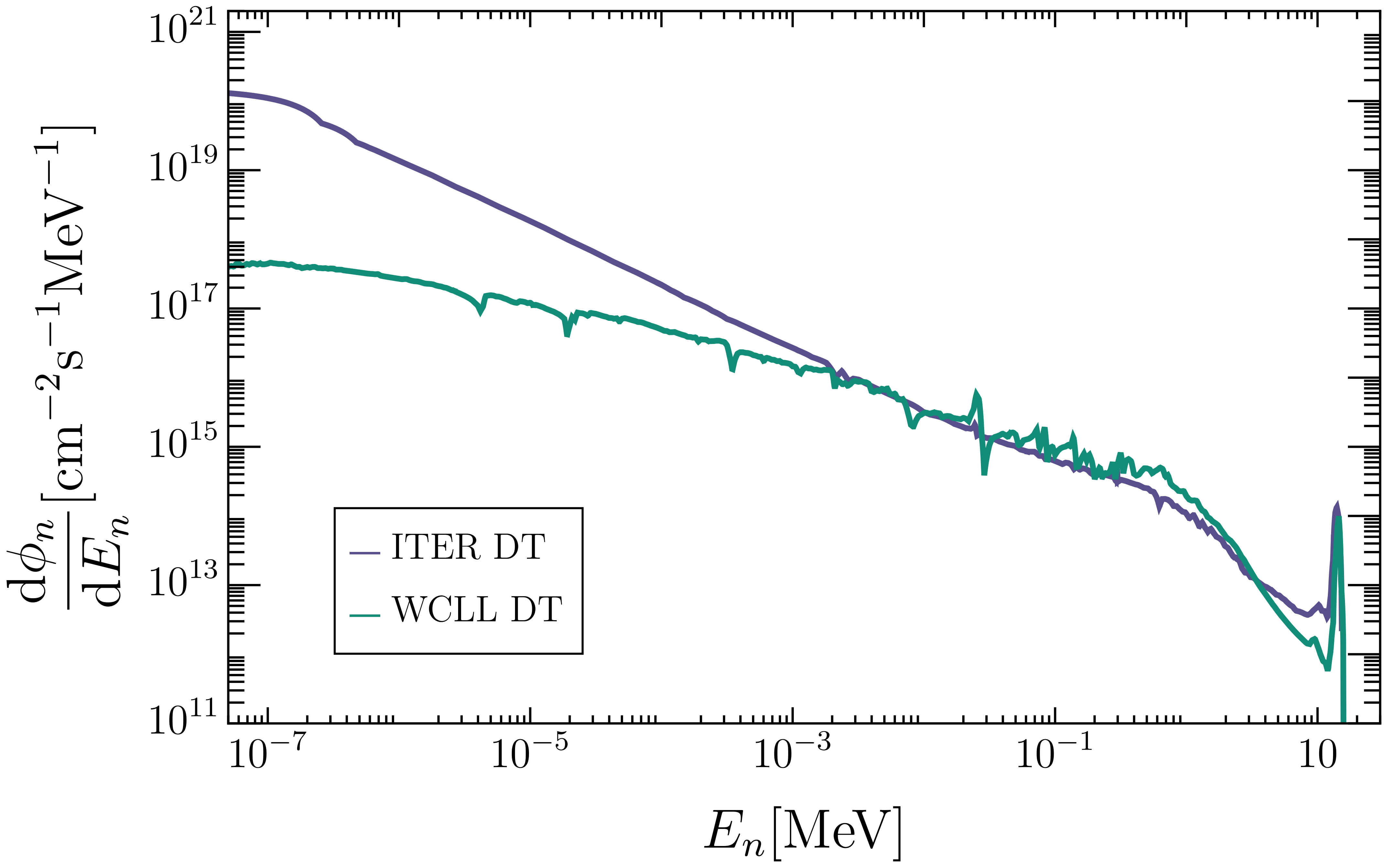
utilize the huge neutron flux

$$\Phi_n^{\text{total}} \sim 10^{15}\text{cm}^{-2}\text{sec}^{-1}$$

energy excess to new particle

$$^2_1\text{D} + ^3_1\text{T} \rightarrow ^4_2\text{He} + n + \varphi$$





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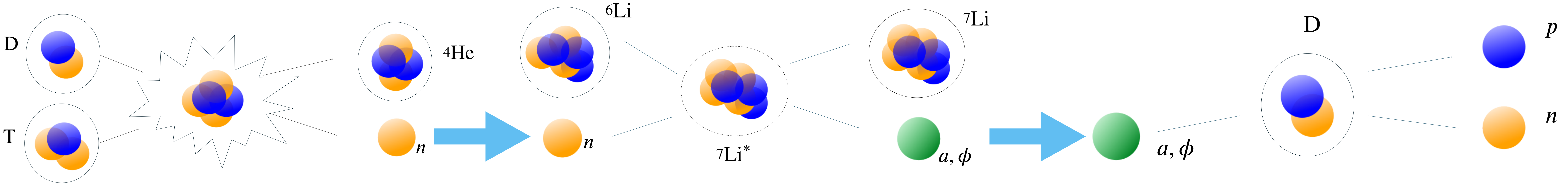
New physics chain

n from the fusion

n on the blanket target

detection via D disassociation
SNO like



$E_\varphi > 2.2$ MeV

number of detected events: $N_\varphi = T N_D \int dE_n dE_\varphi \frac{d\Phi_\varphi}{dE_n} \sigma_{\varphi \mathrm{D} \to np} \propto g_{\varphi p}^4$

operation time

# of deuterium targets

detection cross section

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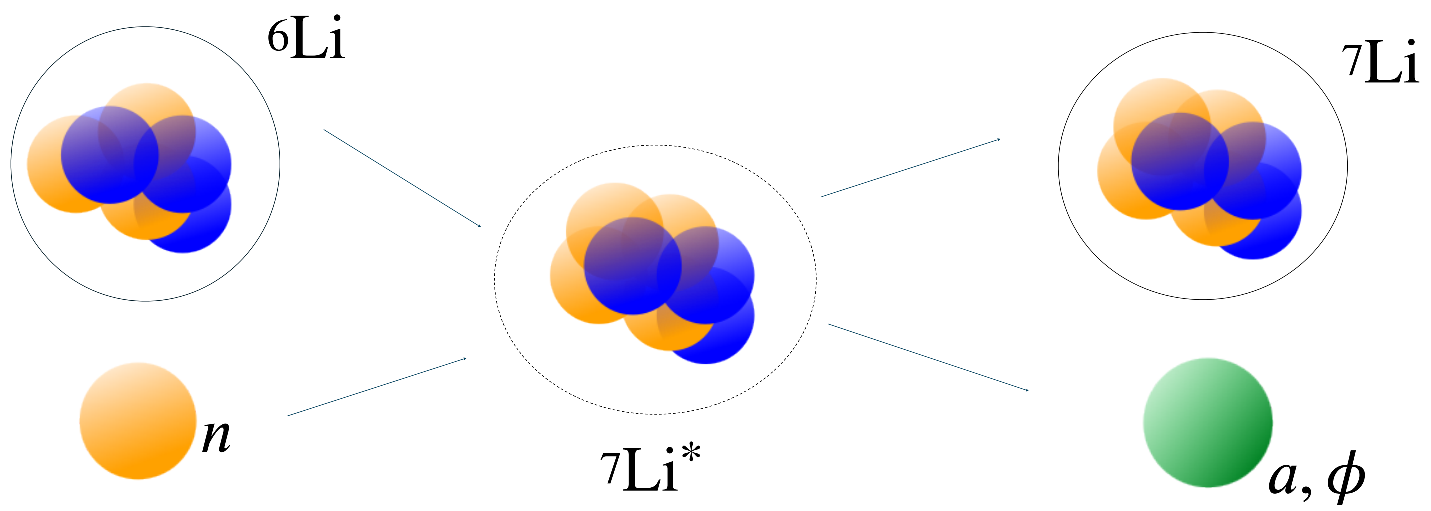
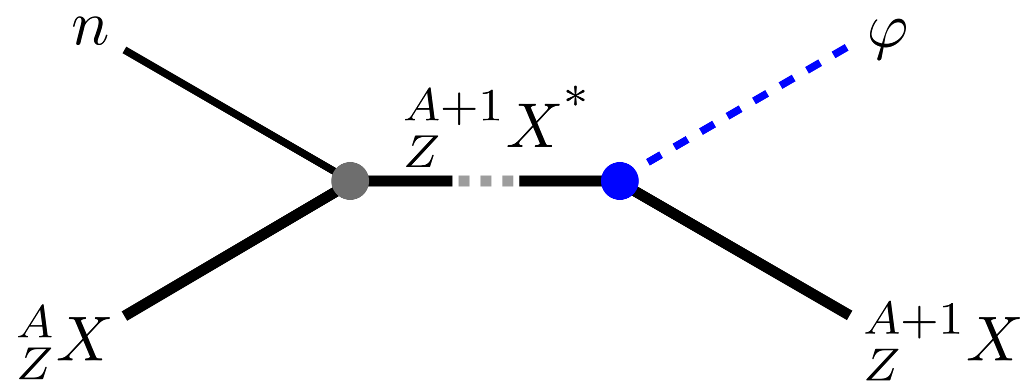
New physics production

utilize the huge neutron flux
+ blanket as a target

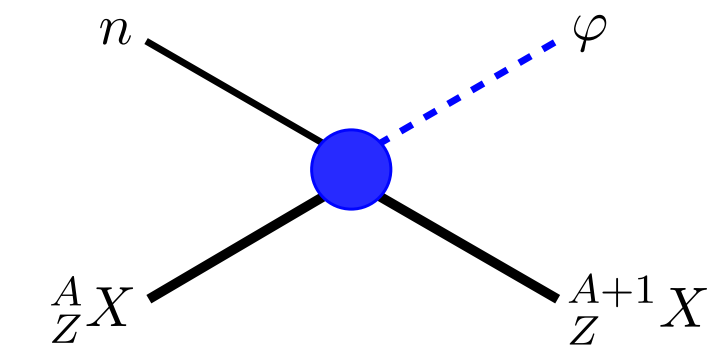


new physics flux

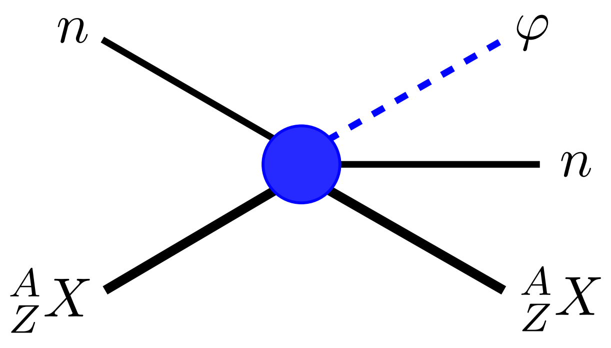
$$\frac{d\Phi_\varphi}{dE_n} = \frac{1}{4\pi L^2}\sum_{i,X} N_X \frac{d\Phi_n}{dE_n}\sigma_\varphi^{i,X}$$



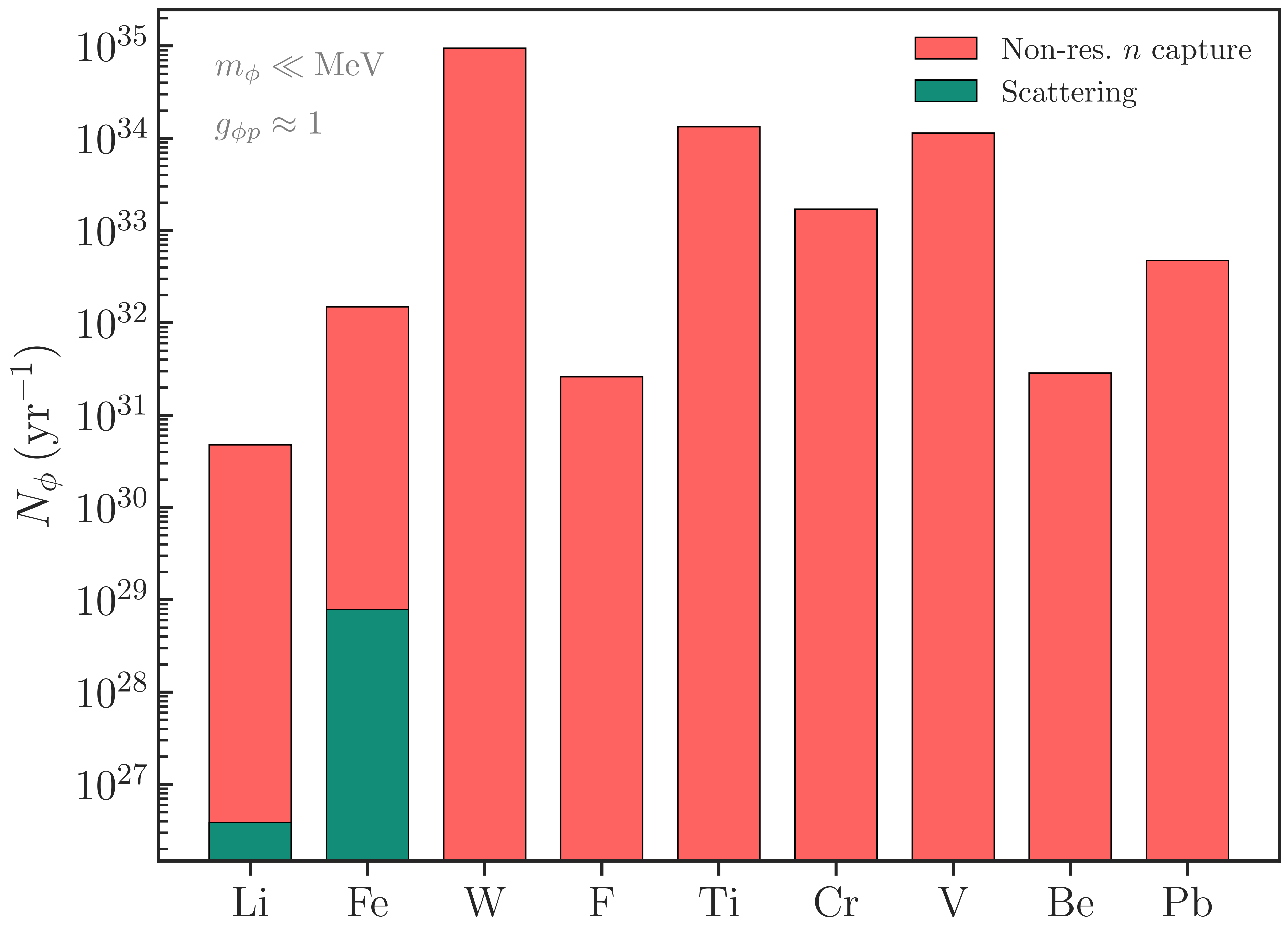
Resonant capture + de-excitation

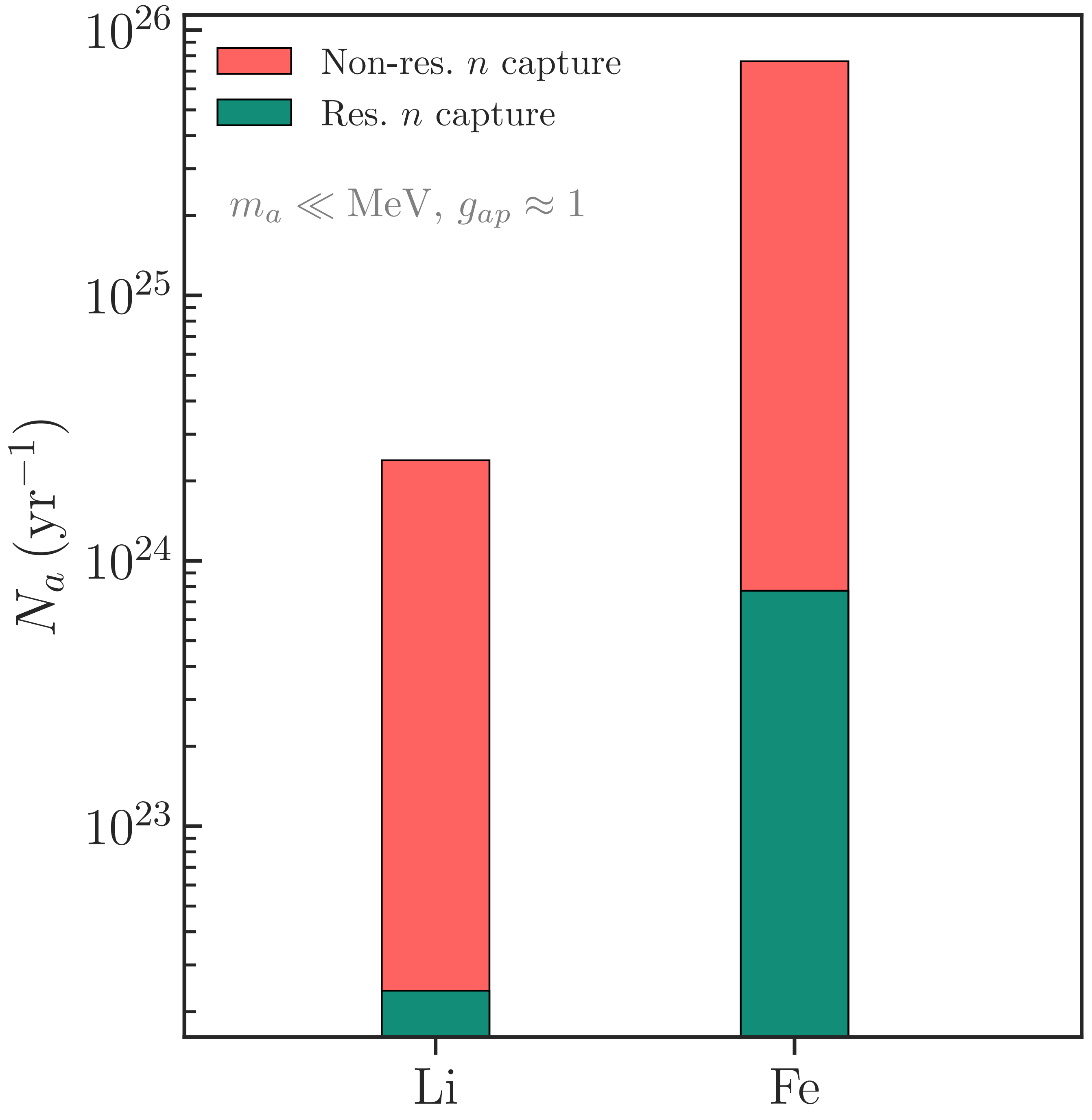


Non-resonant capture + de-excitation



Coherent scattering





$N_X = 10^{29}$ target nuclei, ITER with 2000W

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