4th International Workshop on
Dark Matter, Dark Energy and Matter-Antimatter Asymmetry

Beryllium Decay Anomaly and U(1) Portal to Dark Matter

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based on arXiv:1609.07198 in collaboration with
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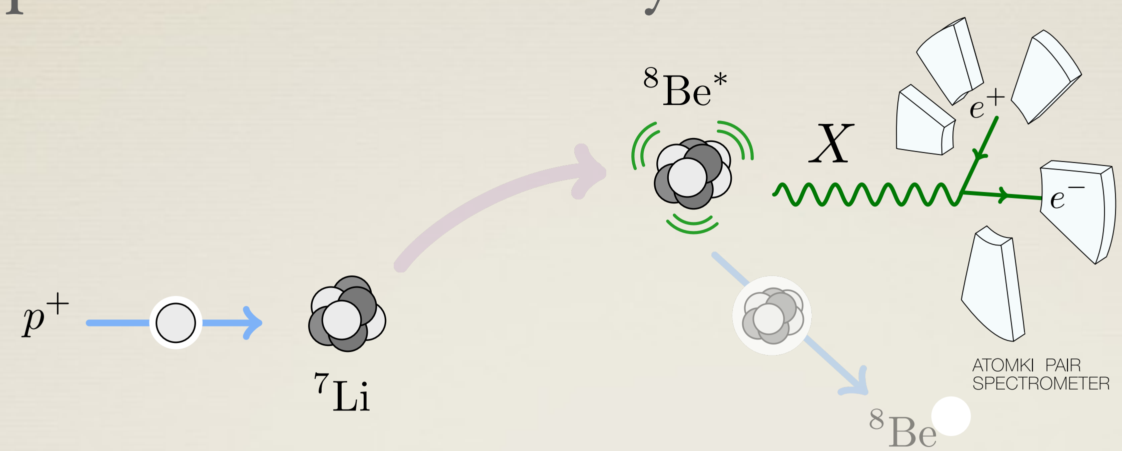
outline

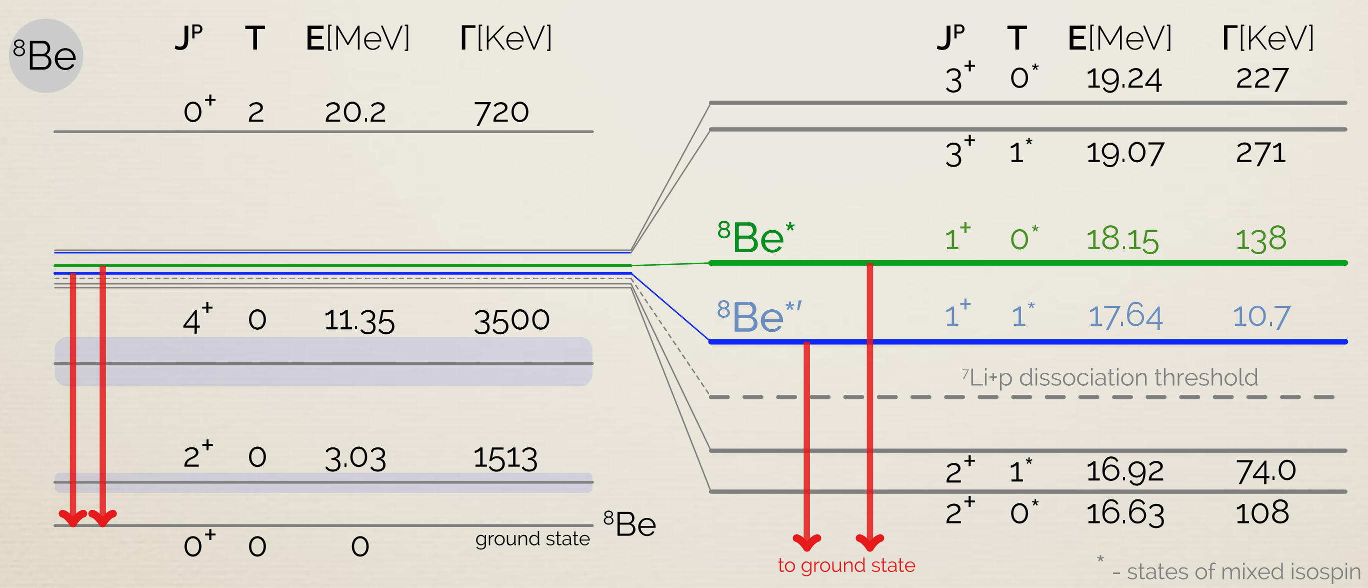
* The ^{8}Be Anomaly
* Hidden U(1) Portal and Experimental Constraints
* Non-hidden U(1) Portal and DM-e scattering search
* Conclusion

1. The ^{8}Be Anomaly

Experiment by Krasznahorkay et al. has recently observed unexpected bumps in both the distributions of open angles and invariant masses of $e^{+}e^{-}$ pairs produced in the decays of an excited ^{8}Be nucleus



J.L.Feng et al. 1608.03591



^{8}Be* —> ^{7}Li + p^{+} mostly

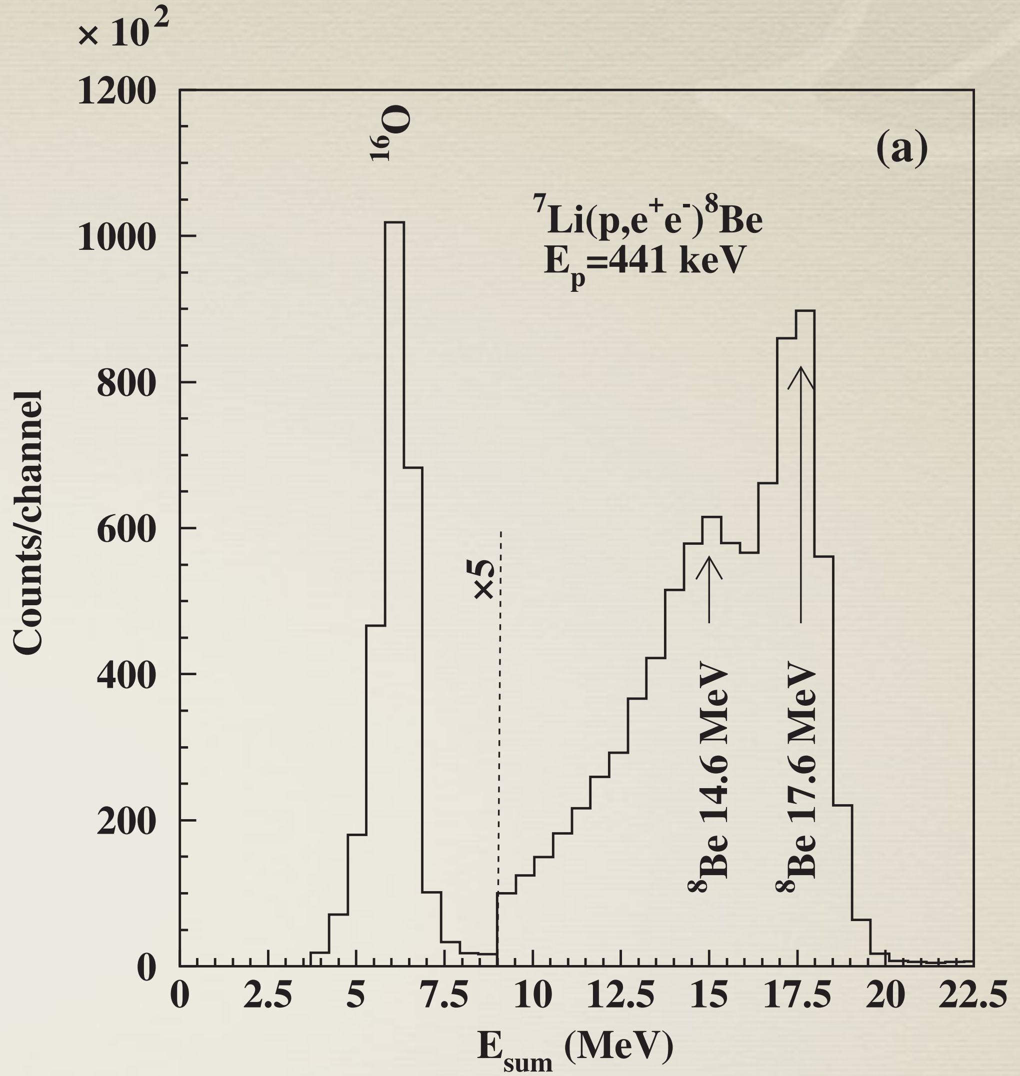
but its electromagnetic transition has $\mathrm{Br}(^{8}\mathrm{Be}^{*} \to {}^{8}\mathrm{Be}\,\gamma) \approx 1.4 \times 10^{-5}$

or $\mathrm{Br}(^{8}\mathrm{Be}^{*} \to {}^{8}\mathrm{Be}\, e^{+}e^{-}) \approx 3.9 \times 10^{-3}\, \mathrm{Br}(^{8}\mathrm{Be}^{*} \to {}^{8}\mathrm{Be}\,\gamma)$

Krasznahorkay et al. have found the bump of θ distribution with 6.8σ statical significance of m_{ee} invariant mass around 17 MeV

$$m_X = 16.7 \pm 0.35\,(\mathrm{stat}) \pm 0.5\,(\mathrm{sys})\ \mathrm{MeV}$$

$$\frac{\Gamma({}^8\mathrm{Be}^* \to {}^8\mathrm{Be}\,X)}{\Gamma({}^8\mathrm{Be}^* \to {}^8\mathrm{Be}\,\gamma)}\,\mathrm{Br}(X \to e^+e^-) = 5.8 \times 10^{-6}$$



Generic hidden U(1) model:

$$\mathcal{L}_{\rm gauge} = -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}\frac{\varepsilon}{\cos\theta_W}Z'_{\mu\nu}B^{\mu\nu} - \frac{1}{4}Z'_{\mu\nu}Z'^{\mu\nu},$$

$$\mathcal{L}_{\rm visible} = -\left(\varepsilon_\gamma e J^\mu_{\rm em} + \varepsilon_Z \frac{g}{2c_W} J^\mu_{\rm NC}\right) Z'_\mu$$

$$J^\mu_{{\rm em},f} = Q_f \bar{f}\gamma^\mu f \quad \text{and} \quad J^\mu_{{\rm NC},f} = (T_{3f} - 2Q_f s_W^2)\bar{f}\gamma^\mu f - T_{3f}\bar{f}\gamma^\mu\gamma_5 f$$

If the Be decay anomaly is due to the mediation of Z' gauge boson ....

$$M_{Z'} = 16.7 \pm 0.35(\text{stat.}) \pm 0.5(\text{sys.})\ \text{MeV}.$$

in this generic framework, Z' can only decay to e^+e^- and $\nu\nu$

$$\Gamma(Z' \to e^+e^-) = \alpha_{\text{em}}(a_e^2 + b_e^2)\frac{M_{Z'}^2 + 2m_e^2}{3M_{Z'}}\sqrt{1 - \frac{4m_e^2}{M_{Z'}^2}}$$

$$\Gamma(Z' \to \nu_i\bar{\nu}_i) = \alpha_{\text{em}}(a_\nu^2 + b_\nu^2)M_{Z'}$$

$$a_f = Q_f\varepsilon_\gamma + \frac{T_{3f} - 2Q_f s_W^2}{2c_W s_W}\varepsilon_Z \quad \text{and} \quad b_f = -\frac{T_{3f}}{2c_W s_W}\varepsilon_Z.$$

Numerically, we have $a_e = -\varepsilon_\gamma - 0.05\varepsilon_Z$, $b_e = -0.6\varepsilon_Z$ and $a_\nu(b_\nu) = -(+)0.6\varepsilon_Z$

The explanation to ^{8}Be* —> ^{8}Be Z′ and other experimental constraints on generic U(1)$_d$ model

$$-\mathcal{L}_{\rm N} = Z'^{\mu}(J^N_{\mu} + J^N_{5\mu})$$

$$J^N_{\mu} = e\varepsilon_p \bar{p}\gamma_\mu p + e\varepsilon_n \bar{n}\gamma_\mu n \text{ and } J^N_{5\mu} = e\varepsilon_{p5}\bar{p}\gamma_\mu\gamma_5 p + e\varepsilon_{n5}\bar{n}\gamma_\mu\gamma_5 n$$

$\langle {}^8{\rm Be}Z'|\mathcal{L}_{\rm N}|{}^8{\rm Be}^*\rangle$ only vector current contributes to the matrix element if parity is conserved.

interesting relation

$$\varepsilon_p = 2a_u + a_d = \varepsilon_\gamma + 0.05\varepsilon_Z = -a_e$$
$$\varepsilon_n = a_u + 2a_d = -0.6\varepsilon_Z = -a_\nu.$$

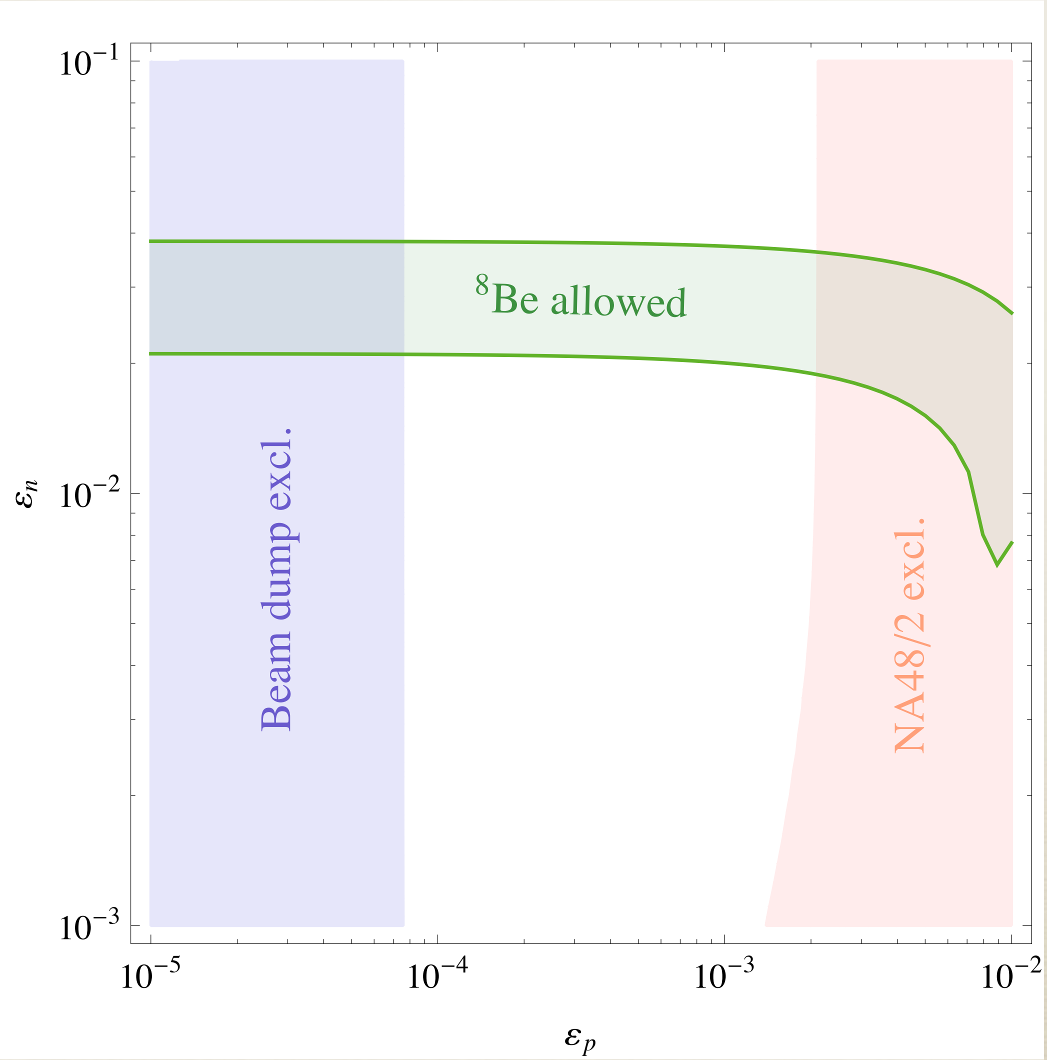
$$\frac{\Gamma({}^8{\rm Be}^* \to {}^8{\rm Be}Z')}{\Gamma({}^8{\rm Be}^* \to {}^8{\rm Be}\gamma)} Br(Z' \to e^+e^-) = 5.8 \times 10^{-6} = (\varepsilon_p + \varepsilon_n)^2 \left[1 - \left(\frac{M_{Z'}}{18.15 \text{ MeV}}\right)^2\right]^{3/2} \frac{\varepsilon_p^2 + \varepsilon_n^2}{\varepsilon_p^2 + 7\varepsilon_n^2}$$

NA48/2 searches for rare neutral pion decays $\pi^0 \to X\gamma \to e^+e^-\gamma$.

$$|\varepsilon_p| \lesssim \frac{(0.8-1.2)\times 10^{-3}}{\sqrt{Br(Z' \to e^+e^-)}}.$$

E141 searches for dark photons bremsstrahlung from e- scatter of target nuclei at SLAC

$$\frac{|a_e|}{\sqrt{Br(Z' \to e^+e^-)}} \gtrsim 2\times 10^{-4}.$$



protophorbic feature is suggested !

However, ν-e scattering experiments

Experiment	$E_\nu(MeV)$	T(MeV)	Events	Cross-Sections	$\sin^2\theta_W$
LSND	$20 < E_\nu < 50$	20-50	191	$[10.1 \pm 1.86] E_\nu \times 10^{-45}\text{cm}^2$	0.248 ± 0.051
LAMPF	$7 < E_\nu < 50$	7-50	236	$[10.1 \pm 1.74] E_\nu \times 10^{-45}\text{cm}^2$	0.249 ± 0.063
IRVINE I	$1.5 < E_\nu < 8$	1.5-3.0	381	$[0.87 \pm 0.25] \times \sigma_{V-A}$	0.29 ± 0.05
IRVINE II	$3.0 < E_\nu < 8.0$	3.0-4.5	77	$[1.70 \pm 0.44] \times \sigma_{V-A}$	0.29 ± 0.05
KRANOYARSK	$3.2 < E_\nu < 8.0$	3.2-5.2	N.A	$[4.5 \pm 2.4] \times 10^{-46}\text{cm}^2/\text{fission}$	$0.22^{+0.7}_{-0.8}$
MUNU	$0.7 < E_\nu < 8.0$	0.7-2.0	68	$[1.07 \pm 0.34] \times \text{events/day}$	$0.25 \pm 0.08^*$
ROVNO	$0.6 < E_\nu < 8.0$	0.6-2.0	41	$[1.26 \pm 0.62] \times 10^{-46}\text{cm}^2/\text{fission}$	$0.29 \pm 0.15^*$
TEXONO	$3.0 < E_\nu < 8.0$	3.0-8.0	414 ± 100	$[1.08 \pm 0.26] \times \sigma_{SM}$	0.251 ± 0.04
Global	-	-	-	-	0.249 ± 0.020

$$|(a_e - a_\nu)a_\nu| \lesssim 8 \times 10^{-9} \quad \text{and} \quad |(a_e + a_\nu)a_\nu| \lesssim 5 \times 10^{-9}$$

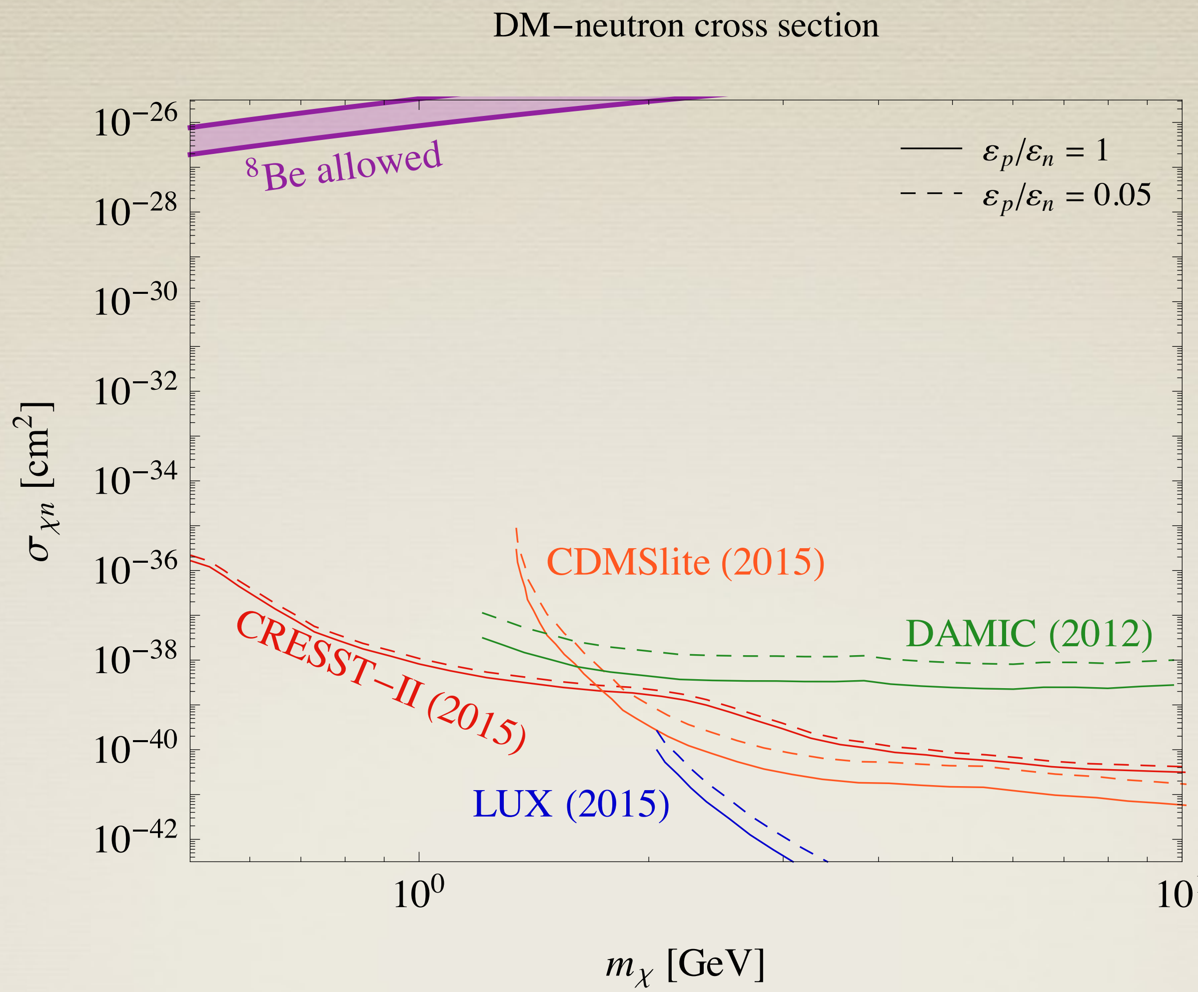
which is so stringent to be incompatible with the “photophobic allowed region” just derived

To accommodate the new light gauge boson indicated in ^{8}Be anomaly as well as U(1) portal scenario, we are led to consider models with non-hidden U(1) gauge symmetry.

Generally, a non-hidden U(1) charge suggests a certain linear combination of SM quantum number and other hidden charge.

Phenomenologically, such models will include a new set of direct gauge-fermion couplings. Thus, the interplay between these couplings will modify the relations among quark and lepton couplings

There are various ways to impose such combinations, here we simply assume those couplings are not correlated and can be alleviated the ν-e scattering constraint



$$\sigma_{\chi \mathrm{A}} = \frac{16\pi\alpha_{\mathrm{em}}\alpha_d\mu_{\chi A}^2}{m_{Z'}^4}[\varepsilon_p Z + \varepsilon_n(A-Z)]^2$$

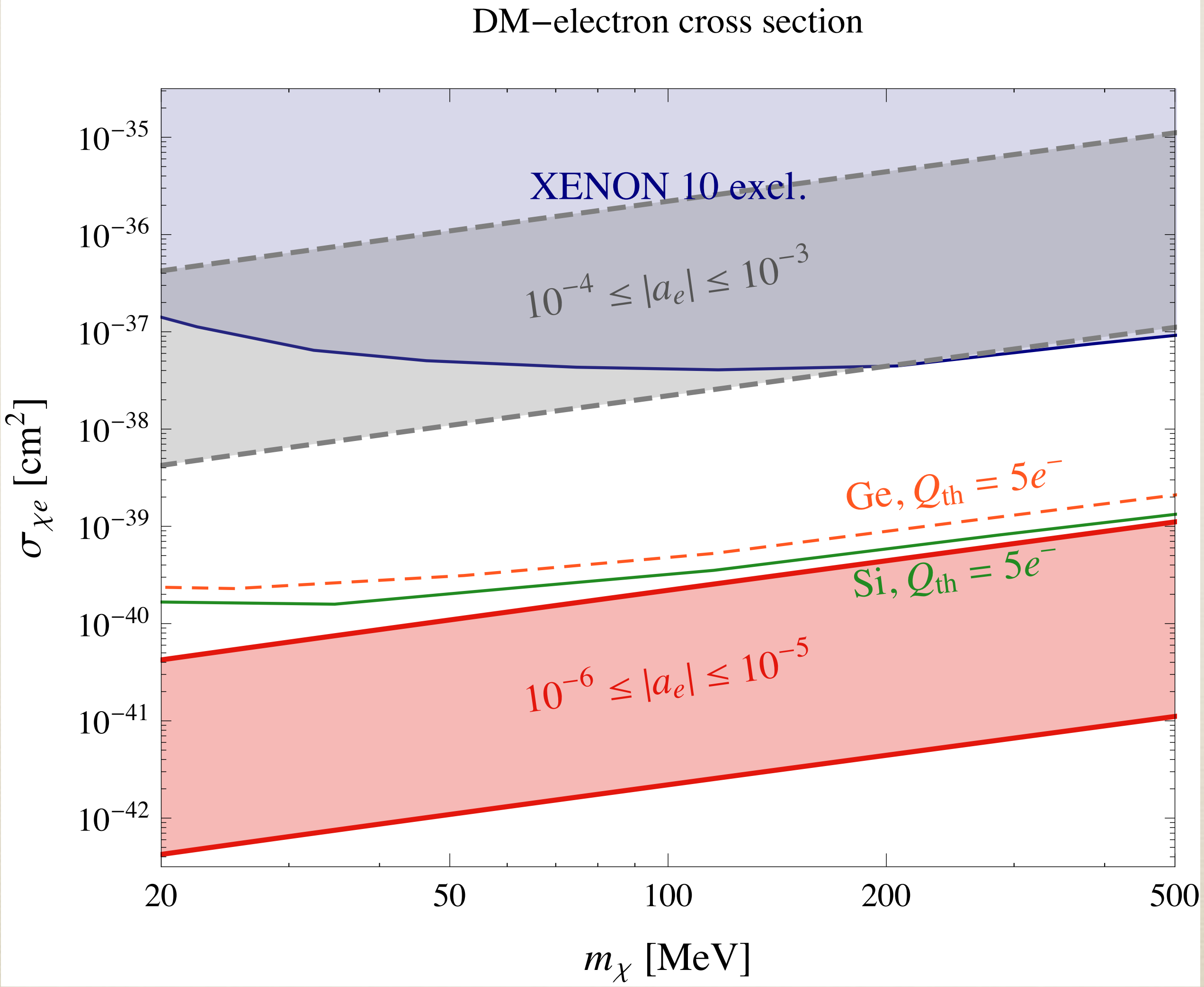
The allowed parameter region of non-hidden U(1) models is excluded by dark matter direct search for dark matter mass is greater than 0.5 GeV

$$\mathcal{L}_{\mathrm{dark}} = e_d\bar{\chi}\gamma^\mu\chi Z'_\mu,$$

DM-electron scattering and MeV-scale DM

For light DM, the recoil of the target nucleus is too small to observe

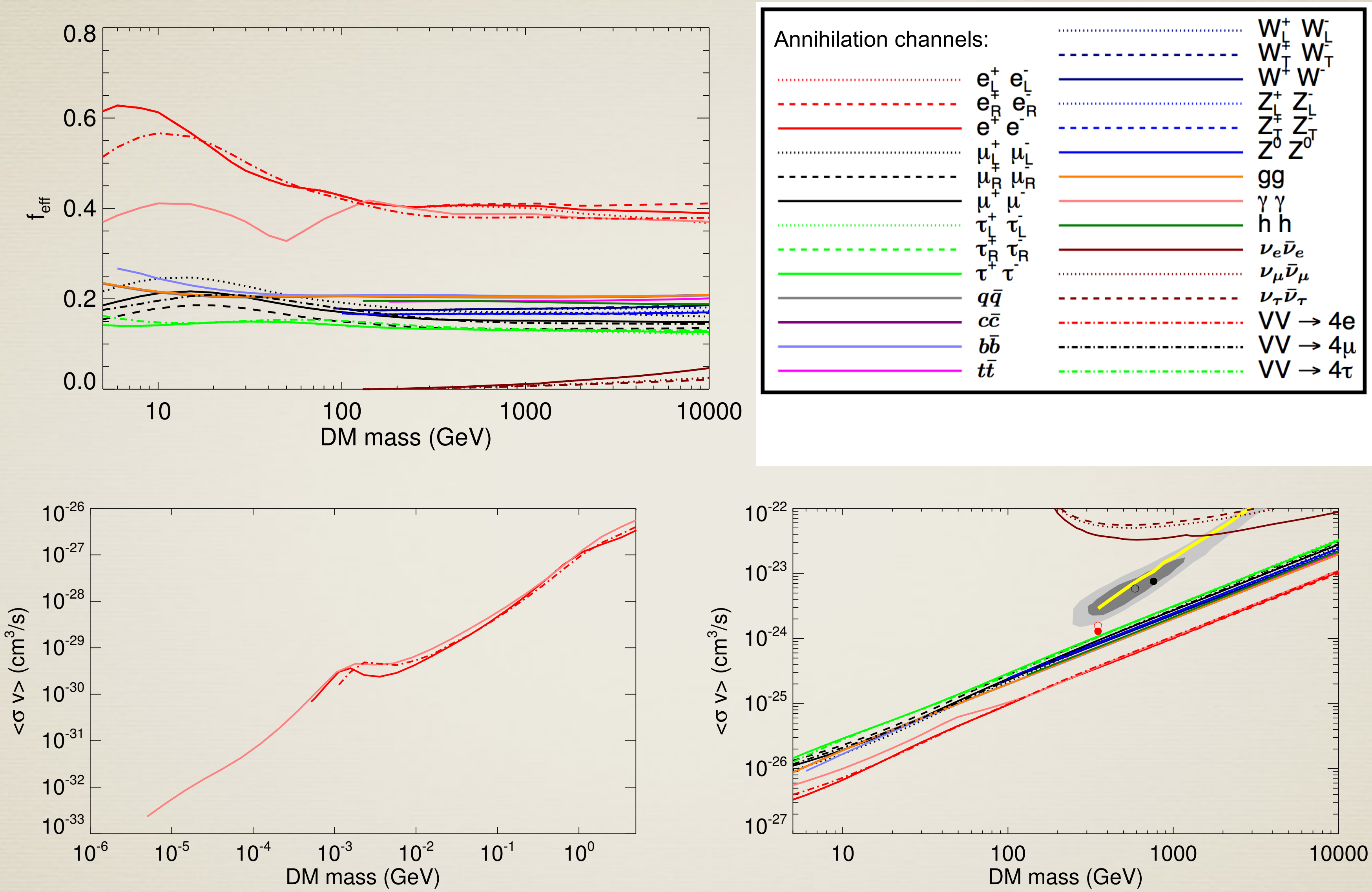
$$\sigma_{\chi e} = 16\pi\alpha_{\rm em}\alpha_d a_e^2 \frac{\mu_{\chi e}^2}{M_{Z'}^4}$$



the lower bounds cutoff at 20 MeV is due to thermal freeze-out and CMB constraints

$$\langle \sigma v \rangle \approx \; 3 \times 10^{-26}\ \mathrm{cm}^3\ \mathrm{s}^{-1}$$

$\chi\chi$ —> z′ —> e^+e^- (or other SM channels if kinematically allowed) the additional injection energy will increase the ionization fraction on the CMB anisotropy and will suppress the power spectrum at small angular scales due to the broadening of the last scattering surface.



General bound on s-wave DM annihilation from Planck (T.R.Slatyer)

$$\langle \sigma v \rangle < 10^{-29} \sim 10^{-30}\ \mathrm{cm^3 s^{-1}}\ \text{for MeV-scale DM}$$

we consider the p-wave process $\chi\chi \to Z'Z'$

therefore, $m_\chi > m_{Z'}$

In addition, the BBN requires the lifetime of Z' to be less than 1 second in the early universe :

$$\varepsilon_Z \gtrsim 6.8 \times 10^{-11} \times \sqrt{17\mathrm{MeV}/m_{Z'}}$$

conclusion

* Beryllium decay anomaly is introduced.

* various experimental constraints are considered, generic $U(1)_{hidden}$ is not compatible with data.

* $U(1)_{non\text{-}hidden}$ dark matter portal scenario for m_χ above 0.5 GeV is also not favored.

* $U(1)_{non\text{-}hidden}$ dark matter portal scenario for MeV scale DM is the remaining possibility, we suggest DM-electron direct search for the sensitivity probe.