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Hunting All the Hidden Photons - and more?

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based on

Bauer, Foldenauer, Jaeckel, [JHEP07 \(2018\) 094](#)
Foldenauer, [arXiv:1808.03647](#)

Motivation

- We have ample evidence for DM, but internal dynamics of dark sector is an open question.



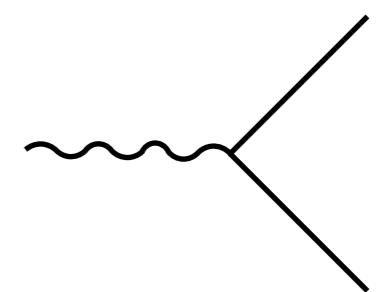
- If we add extra U(1), gauge invariance and renormalizability allow for the kinetic mixing portal term.

$$\mathcal{L}_{\text{kin}} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{\epsilon}{2}F_{\mu\nu}F'^{\mu\nu}$$


A diagram showing a crossed wavy line, representing the kinetic mixing portal term. The wavy line consists of two intersecting horizontal lines, each ending in a wavy end.

- Bringing kinetic terms into canonical form:

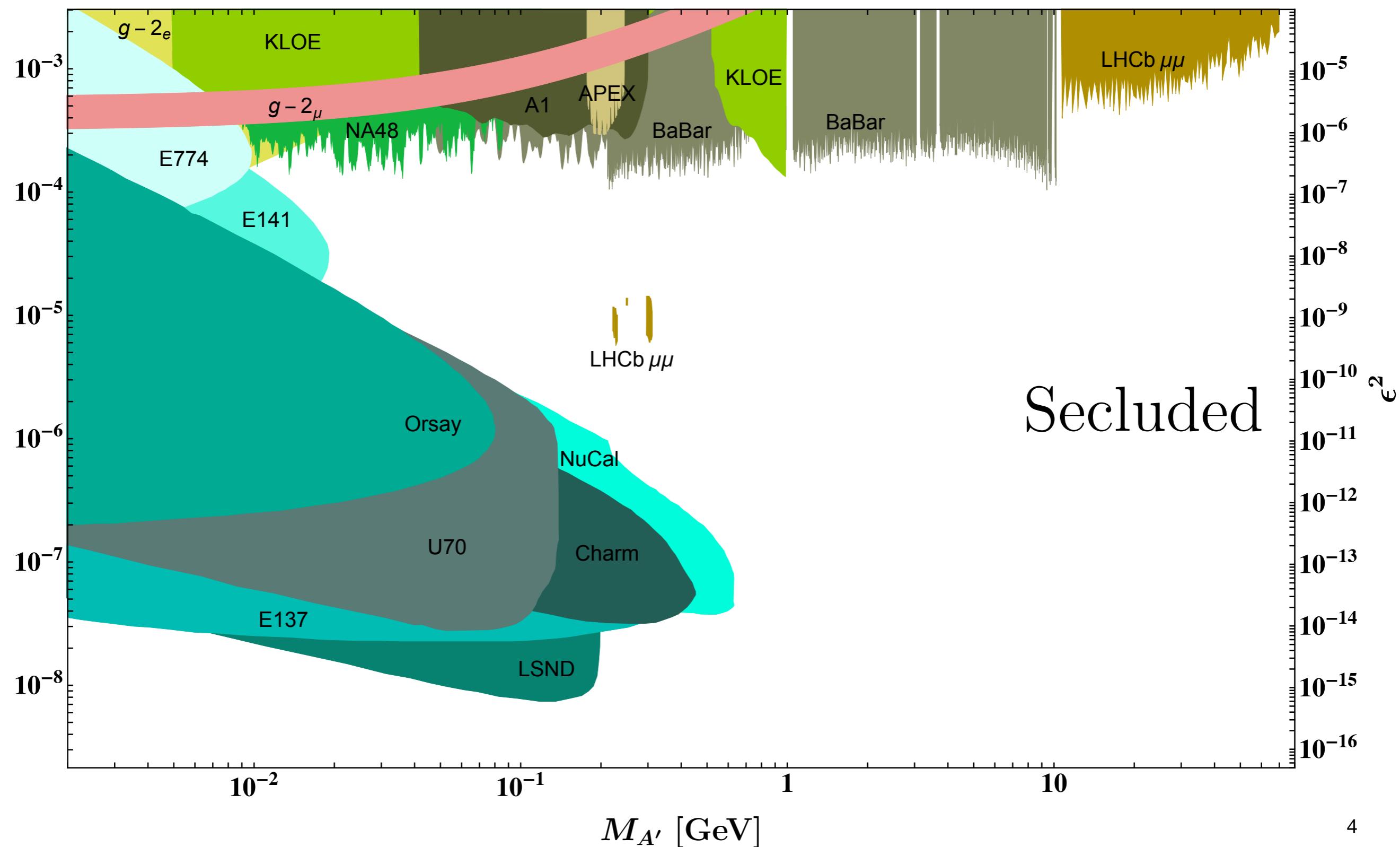
$$A^\mu \rightarrow A^\mu - \epsilon A'^\mu \quad \rightarrow \quad eA_\mu J_{\text{EM}}^\mu - \epsilon e A'_\mu J_{\text{EM}}^\mu$$



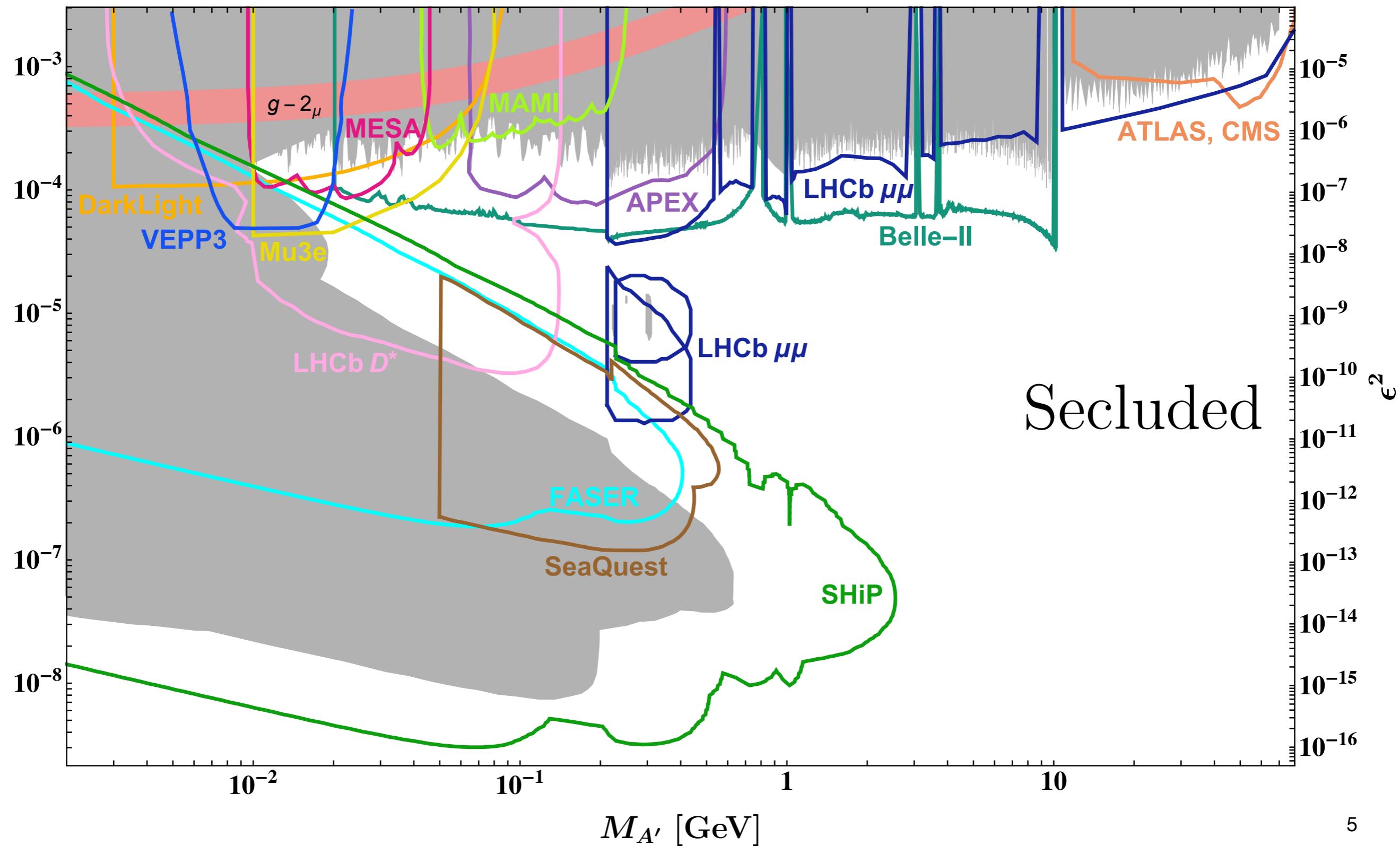
Secluded Hidden Photon

No SM fields are charged under the new U(1) symmetry.

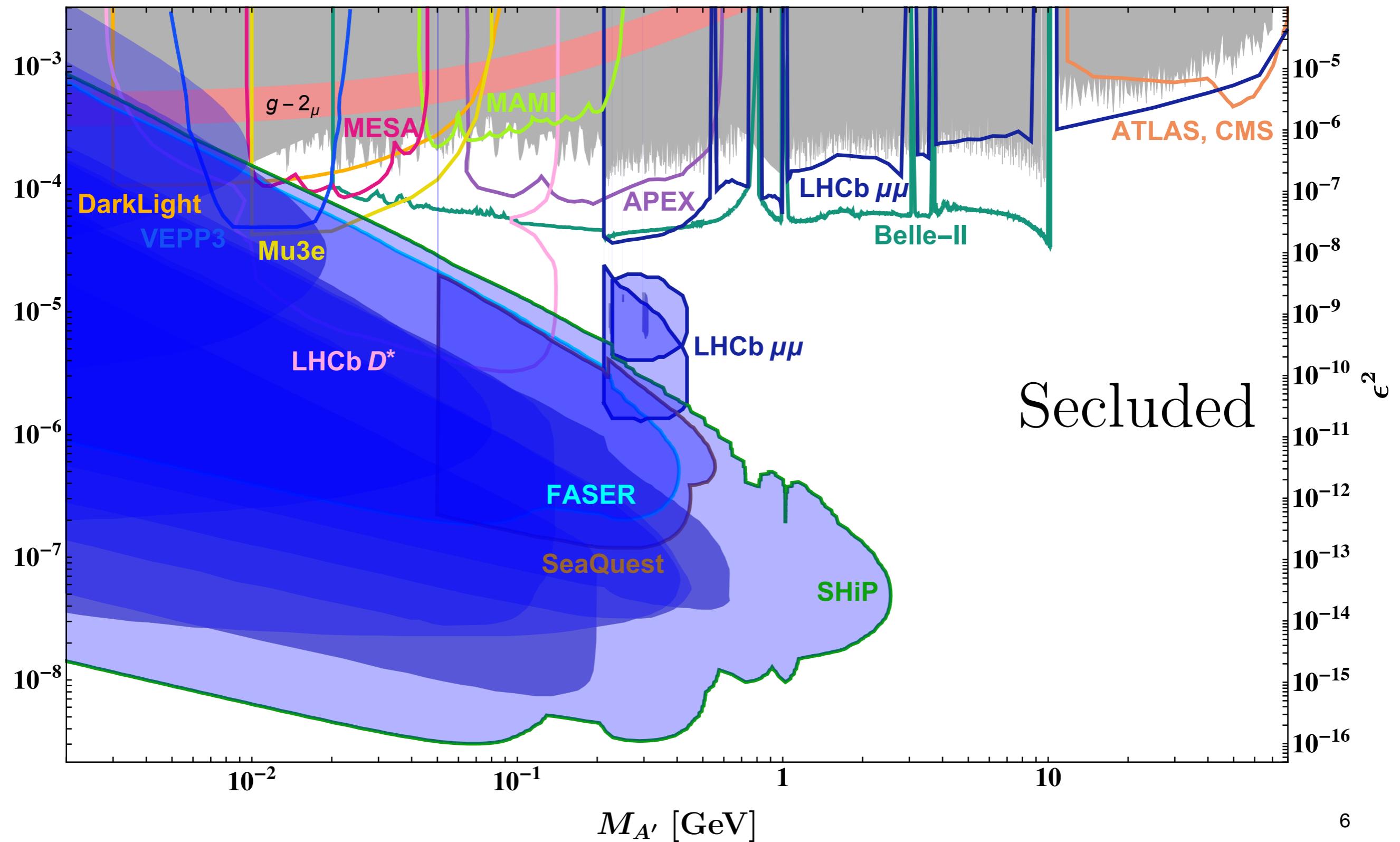
Secluded $U(1)_X$ - current status



Secluded $U(1)_X$ - future sensitivity

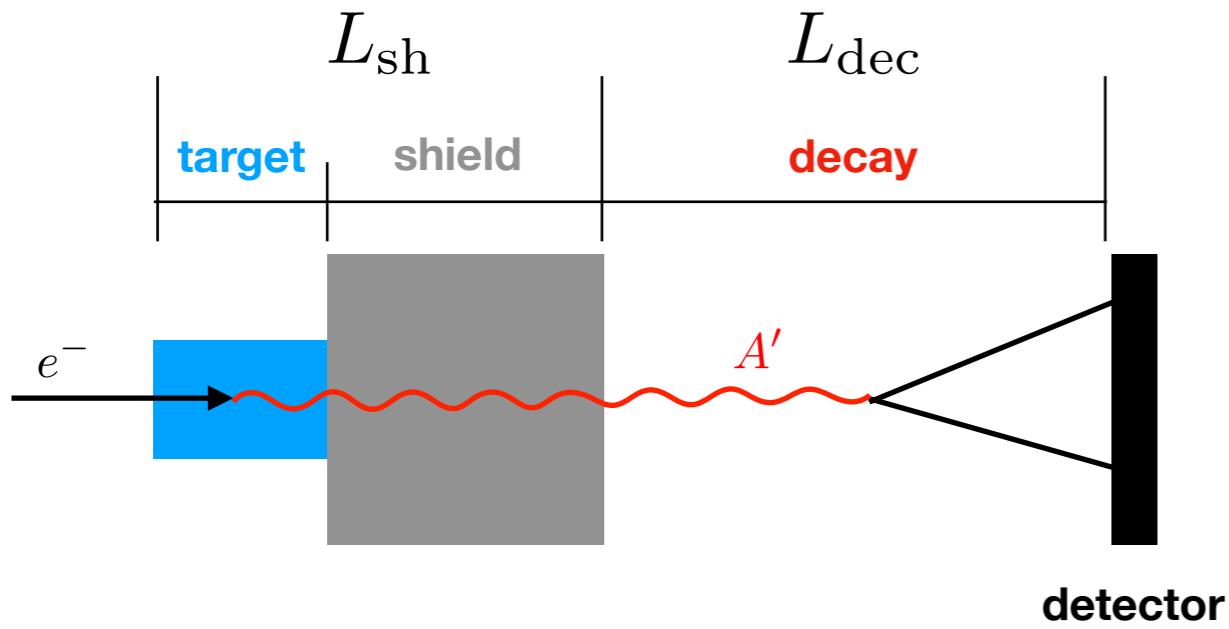


Displaced searches

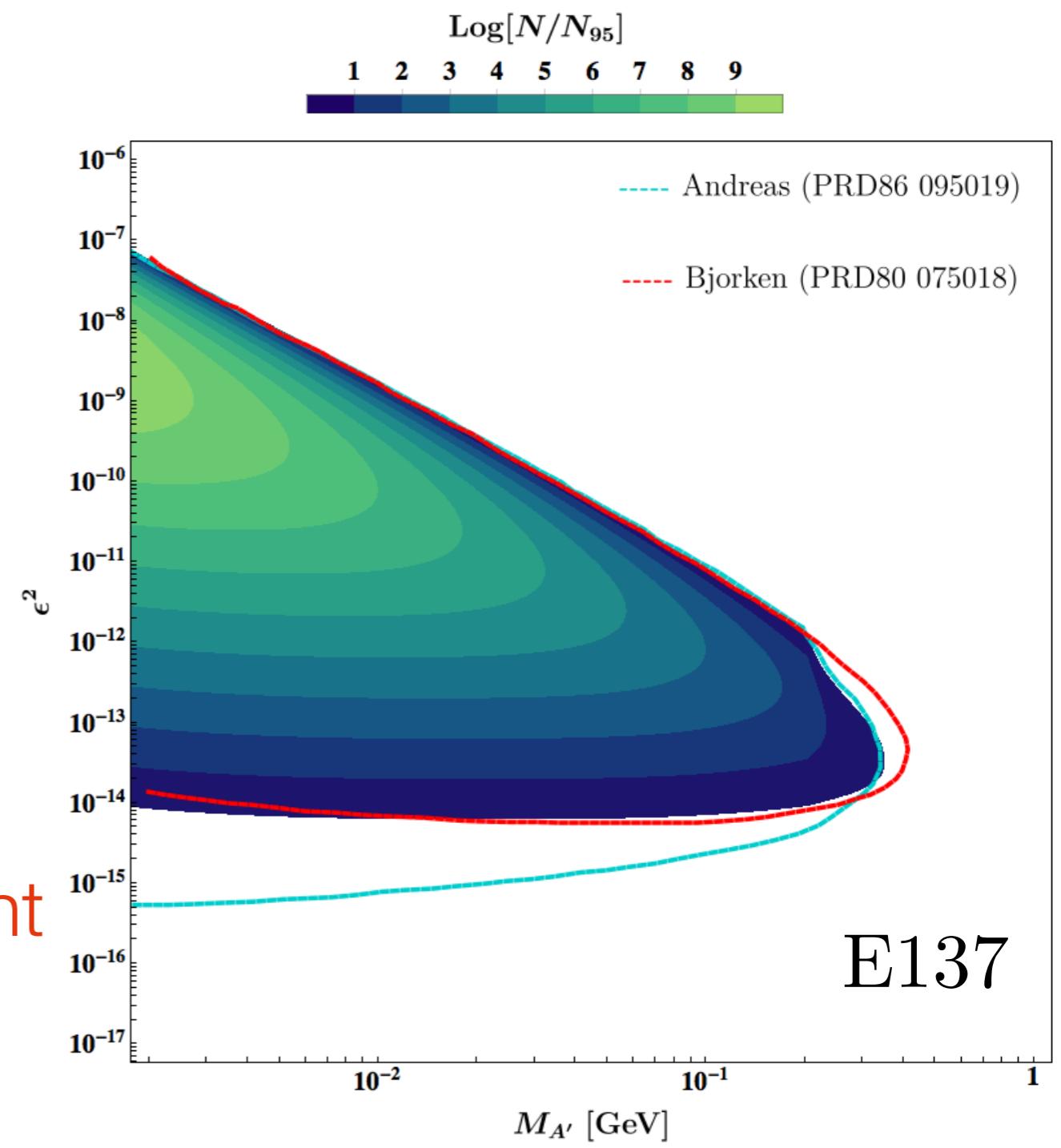
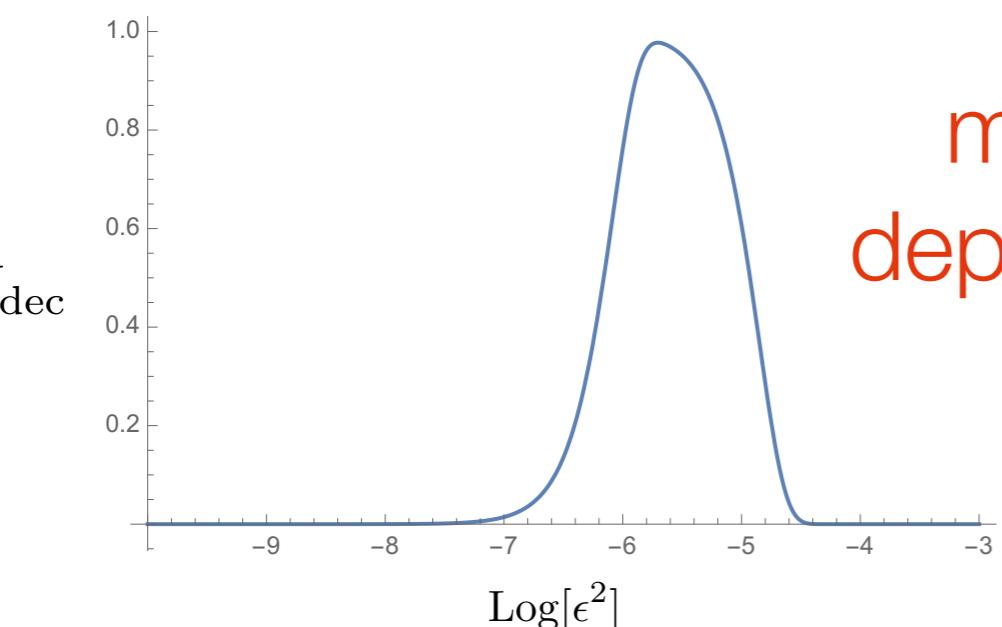


Beam dumps – ideal HP experiments

A' naturally light and weakly coupled: $M_{A'} \propto g' \langle \phi \rangle$



$$N_{\text{dec}} \propto e^{-\frac{L_{\text{sh}}}{\ell_{A'}}} \left(1 - e^{-\frac{L_{\text{dec}}}{\ell_{A'}}} \right)$$



Anomaly-free gauge groups

Some SM fields are charged under the new U(1) symmetry.

Charging SM fields under extra U(1)

- Four extra anomaly-free groups within the SM:

B - L

charging
quarks &
leptons

$L_\mu - L_e$

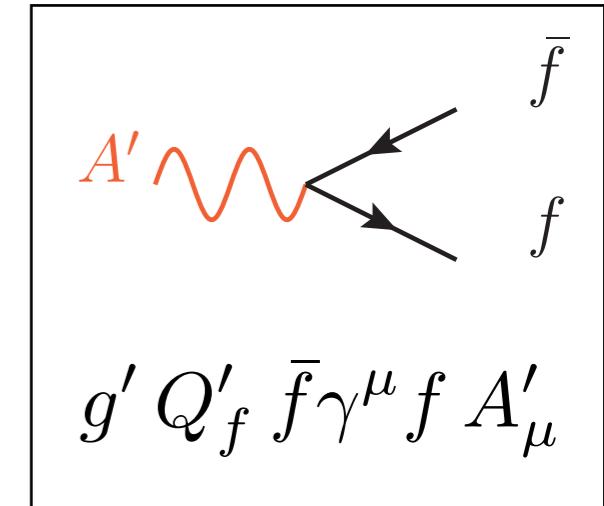
charging 1st &
2nd generation
leptons

$L_e - L_\tau$

charging 1st &
3rd generation
leptons

$L_\mu - L_\tau$

charging 2nd &
3rd generation
leptons



- Loop-induced mixing is unavoidable!
However, it is finite and calculable for $L_i - L_j$:

$$\text{Diagram: A photon } \gamma \text{ with momentum } q \text{ enters a loop. Inside the loop, a lepton } \ell_{i,j} \text{ and its neutrino } \nu_{i,j} \text{ are shown. A red wavy line } A' \text{ exits the loop. The result is proportional to } \frac{\epsilon_{ij}(q^2)}{2} F^{\mu\nu} F'_{\mu\nu}.$$

$$\epsilon_{ij}(q^2) \simeq \frac{3e g_{ij}}{4\pi^2} \int_0^1 dx x(1-x) \log \left(\frac{m_i^2 + q^2 x(x-1)}{m_j^2 + q^2 x(x-1)} \right)$$

White dwarf cooling

- Hidden photons can modify plasmon decay and generate extra neutrino cooling of white dwarfs.

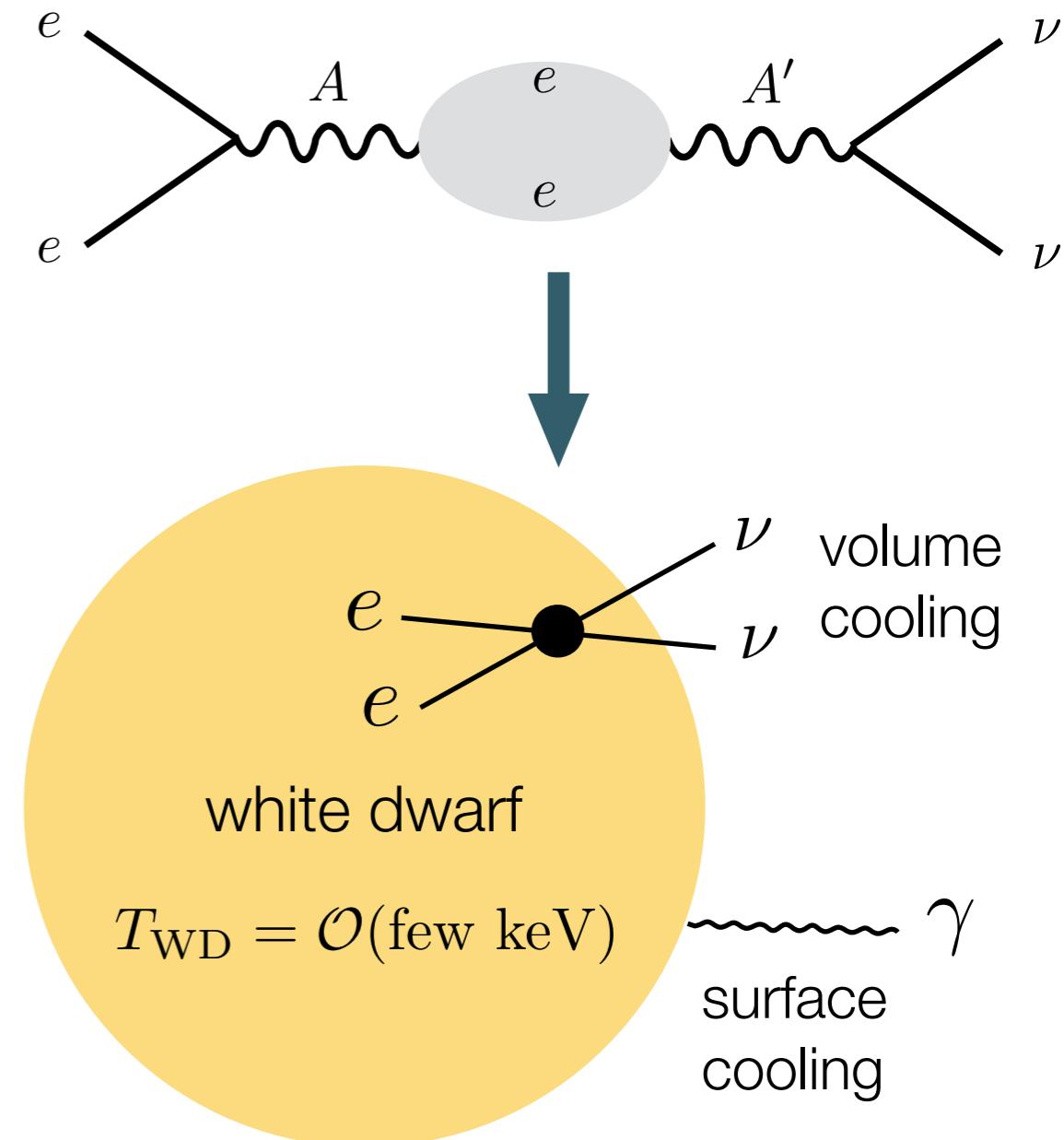
- A limit can be set on the Wilson coefficient of the operator

$$\mathcal{L} = C_{\text{WD}} (\bar{\nu} \gamma_\mu P_L \nu)(\bar{e} \gamma_\mu e)$$

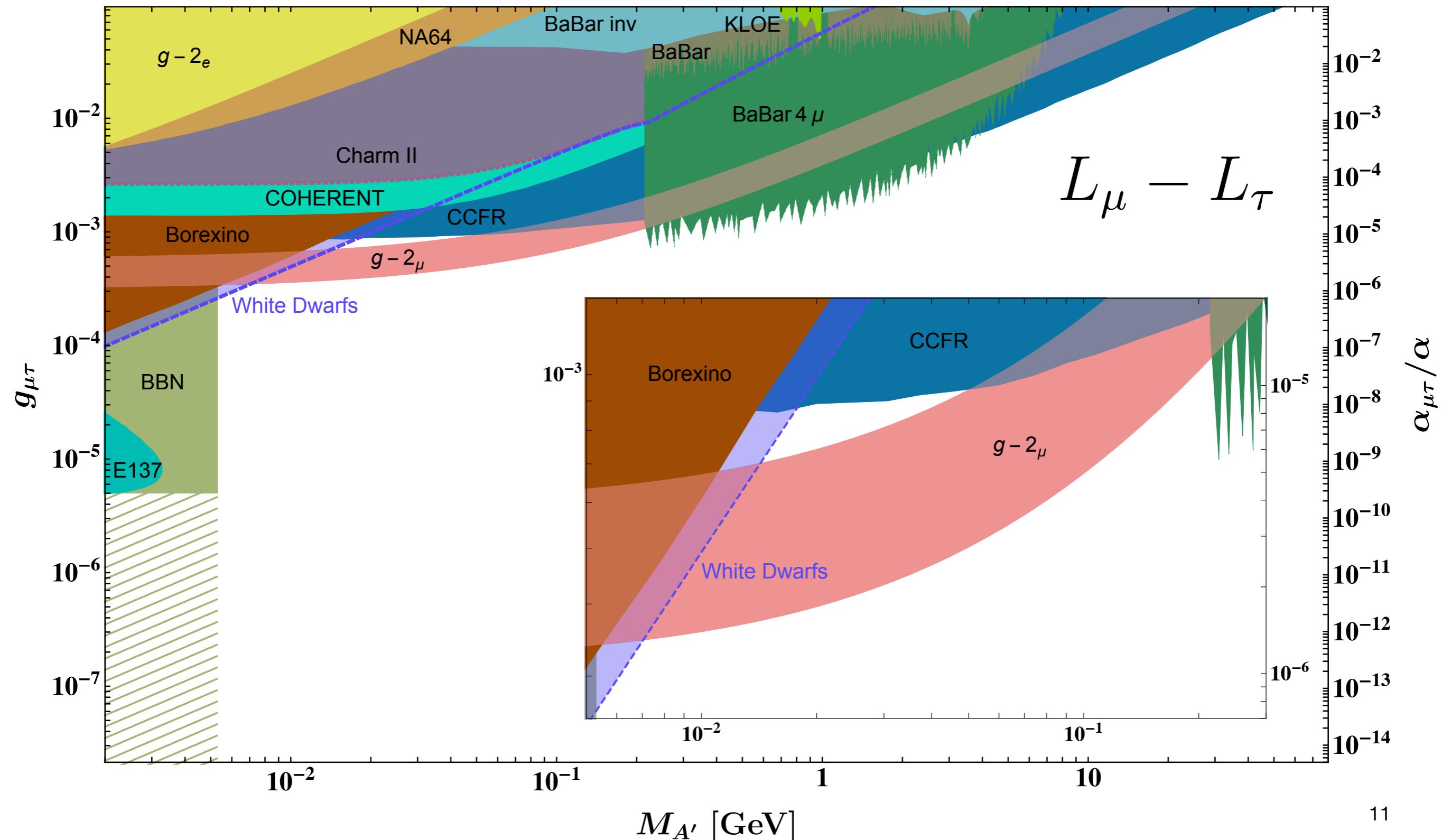
where for a hidden photon

$$C_{\text{WD}} = \frac{N_\nu 4\pi}{3M_{A'}^2} \alpha' Q'_e$$

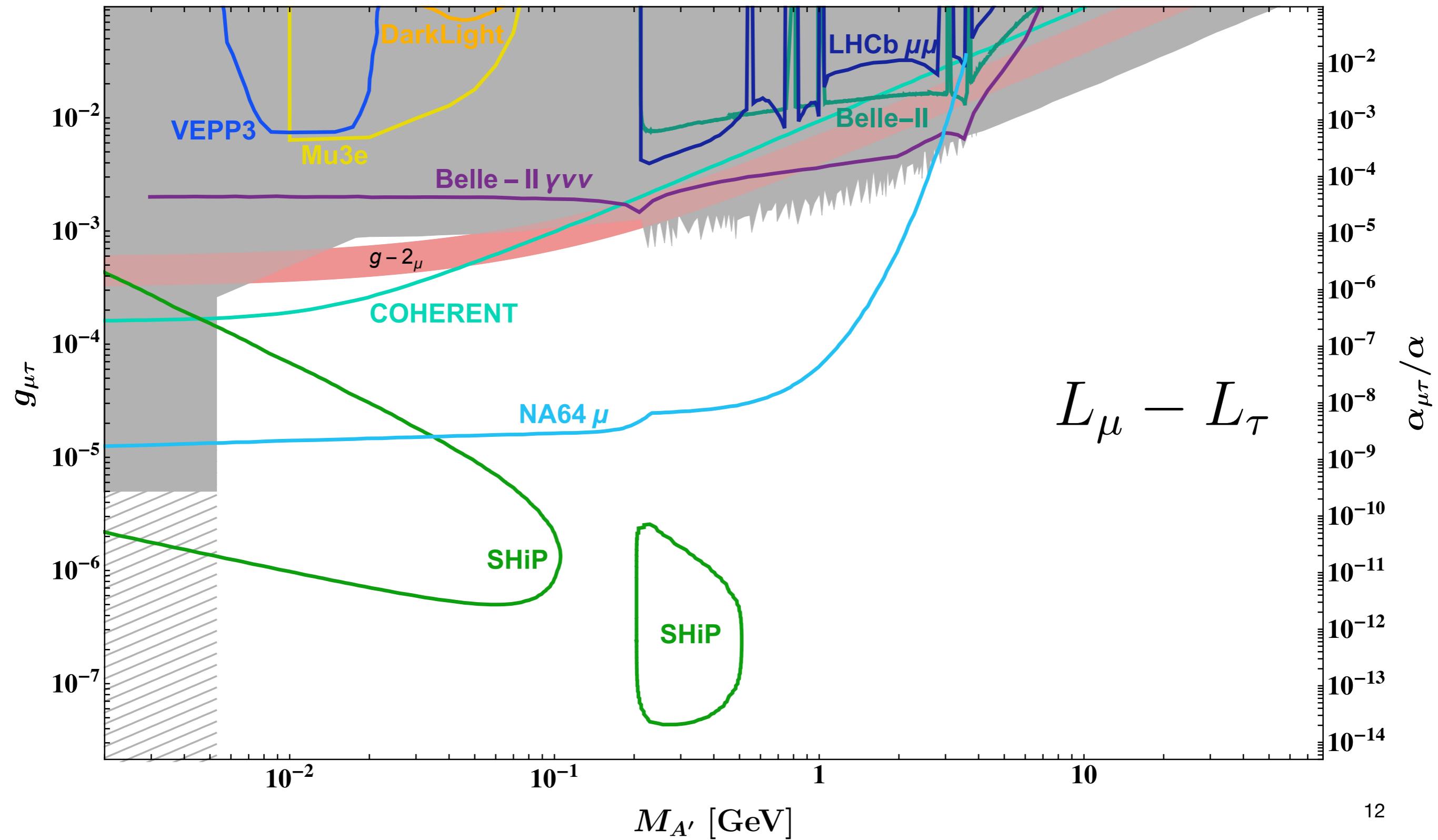
$$\frac{1.12 \times 10^{-5}}{\text{GeV}^2} < C_{\text{WD}} < \frac{4.50 \times 10^{-3}}{\text{GeV}^2}$$



$L_\mu - L_\tau$ - current status



$L_\mu - L_\tau$ - future sensitivity

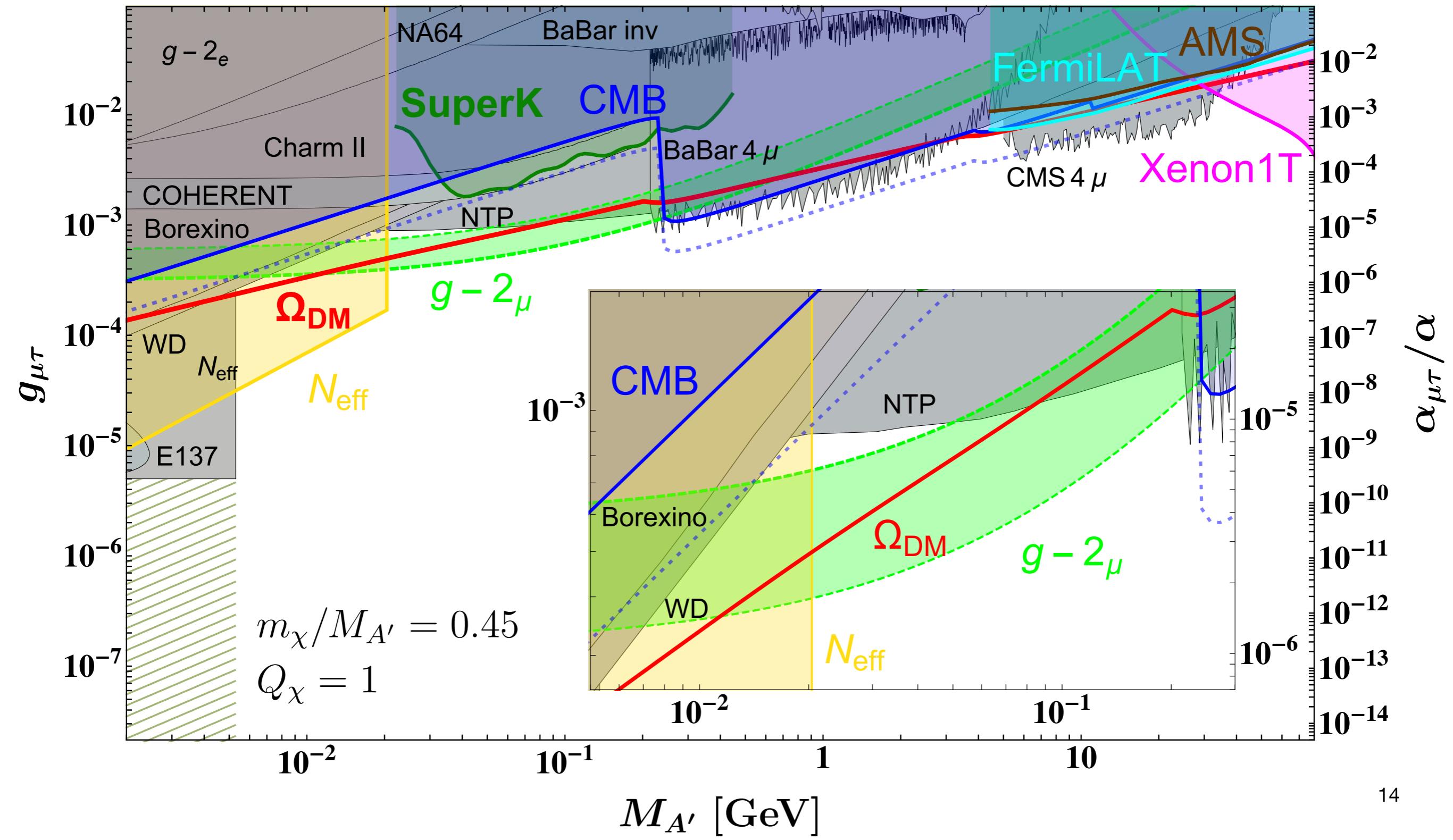


Let there be light DM

Augment field content by light vector-like fermion charged under $U(1)_{L_\mu - L_\tau}$.

Vector-like DM within $U(1)_{L_\mu - L_\tau}$

- Add a vector-like fermion: $\mathcal{L} = -g_{\mu\tau} Q_\chi \bar{\chi} \gamma^\mu \chi A'_\mu$



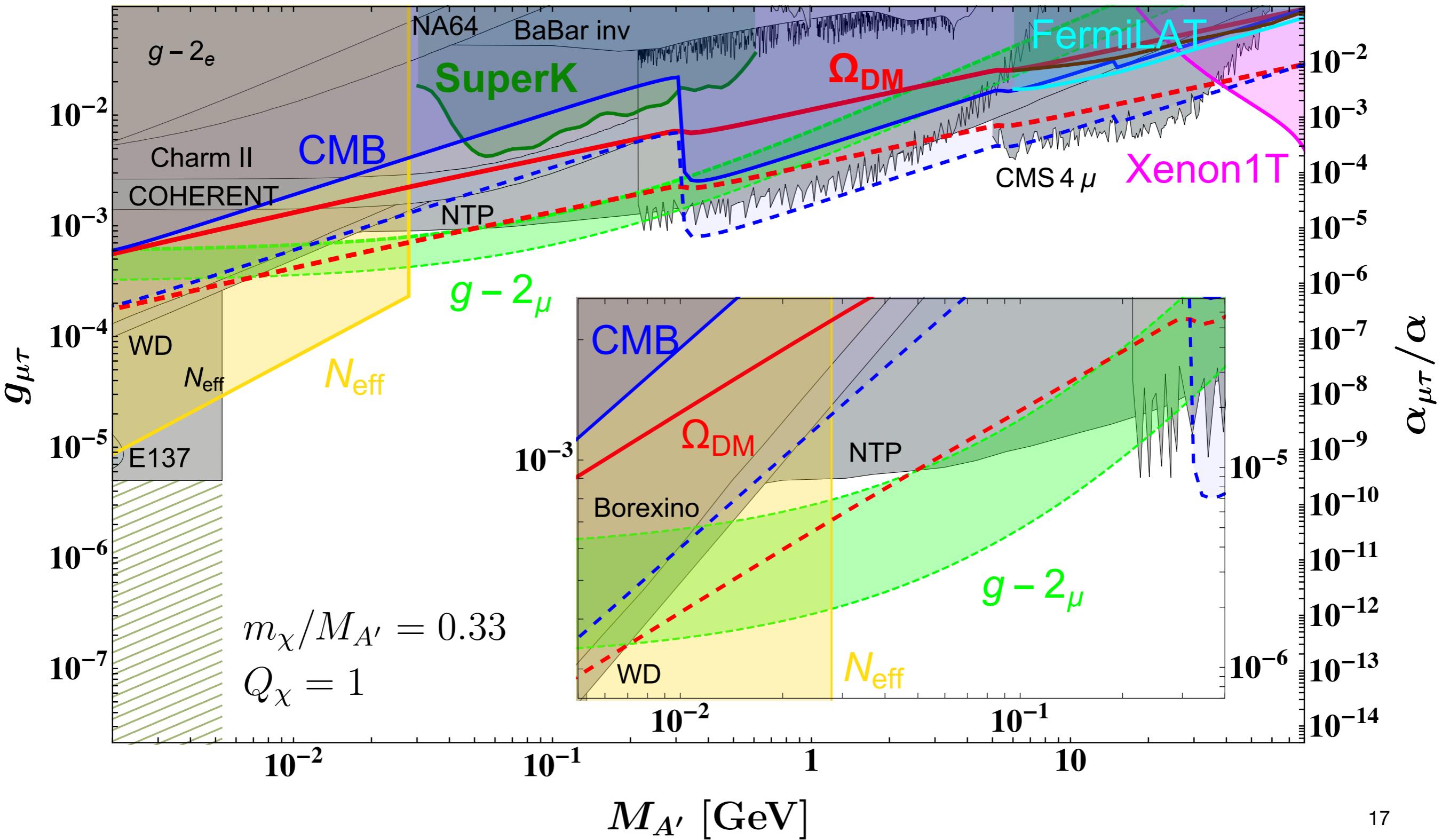
Conclusions

- Gauge couplings to SM particles can **dramatically reshape** the landscape of **HP constraints**.
→ Different experiments are sensitive to different scenarios!
- New **white dwarf limit** improved over previous Borexino constraints and **rules out** part of the $(g - 2)_\mu$ explanation of $L_\mu - L_\tau$.
- Future experiments like Belle-II, SHiP and a dedicated muon run of NA64 could rule out large part of parameter space.
- **Simultaneous explanation** of $(g - 2)_\mu$ and Ω_{DM} in extended $U(1)_{L_\mu - L_\tau}$.

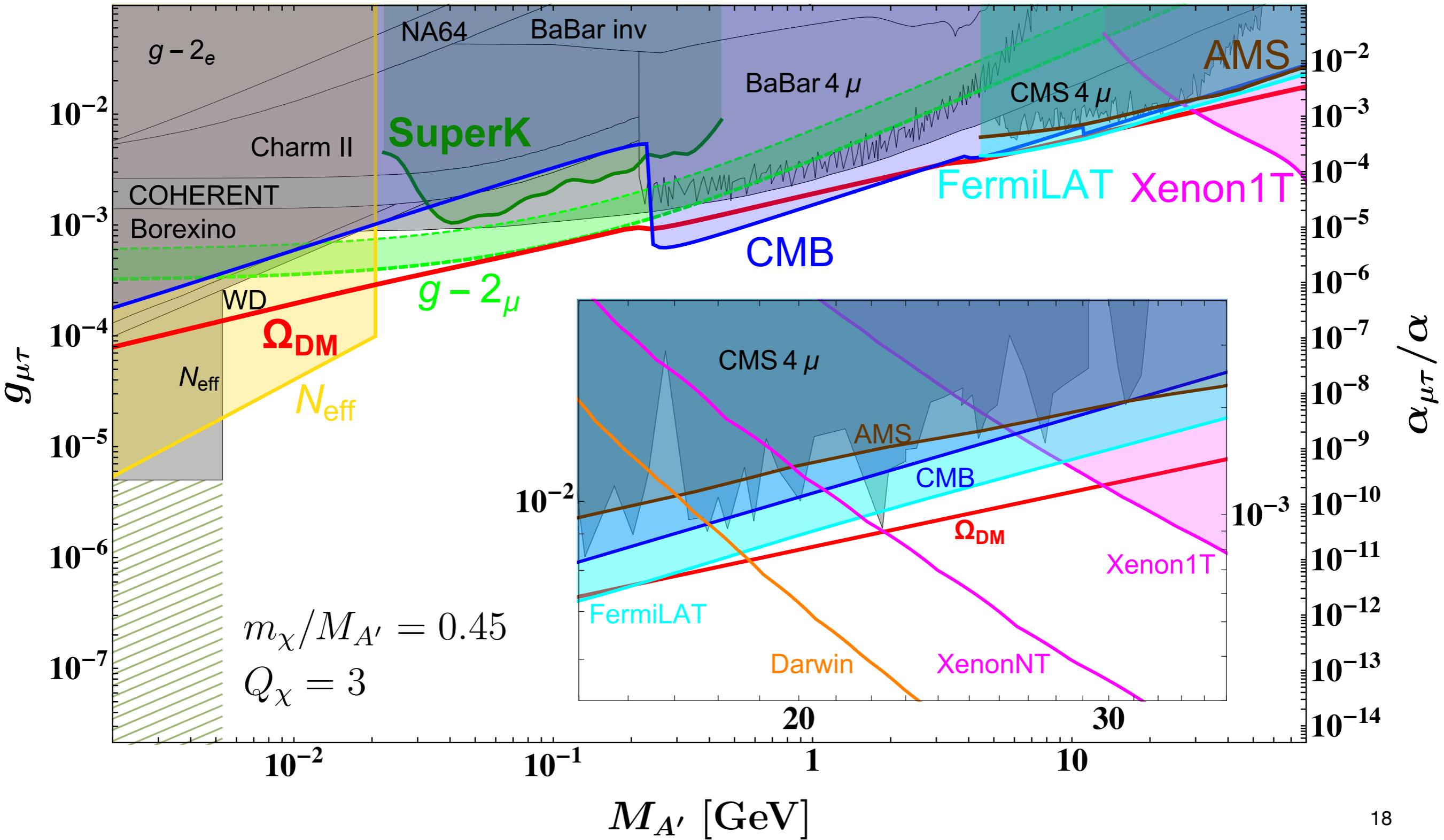
Thank you for your attention!

Backup

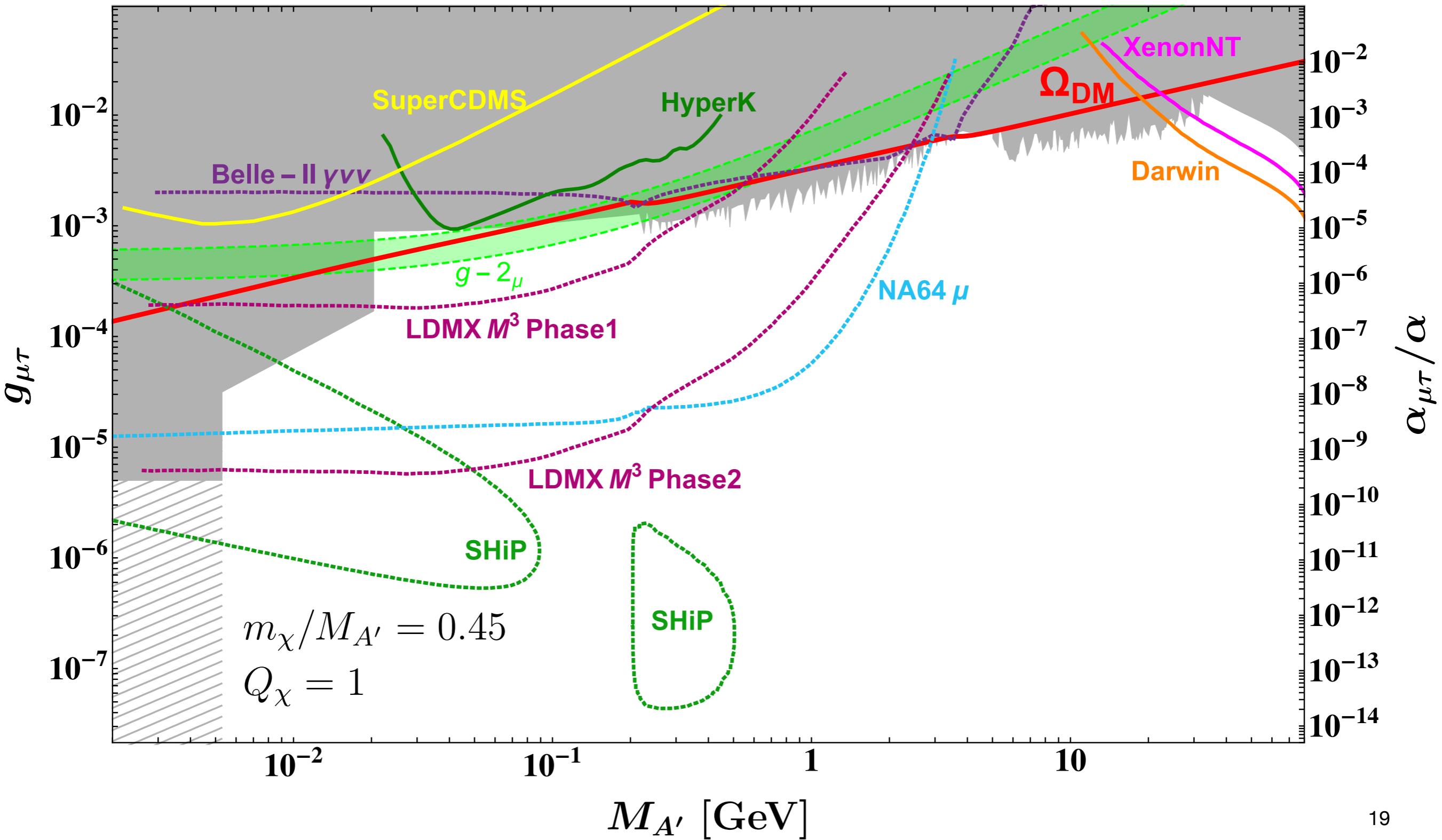
$L_\mu - L_\tau$ DM – Standard Benchmark



$L_\mu - L_\tau$ DM – Non-unit charge

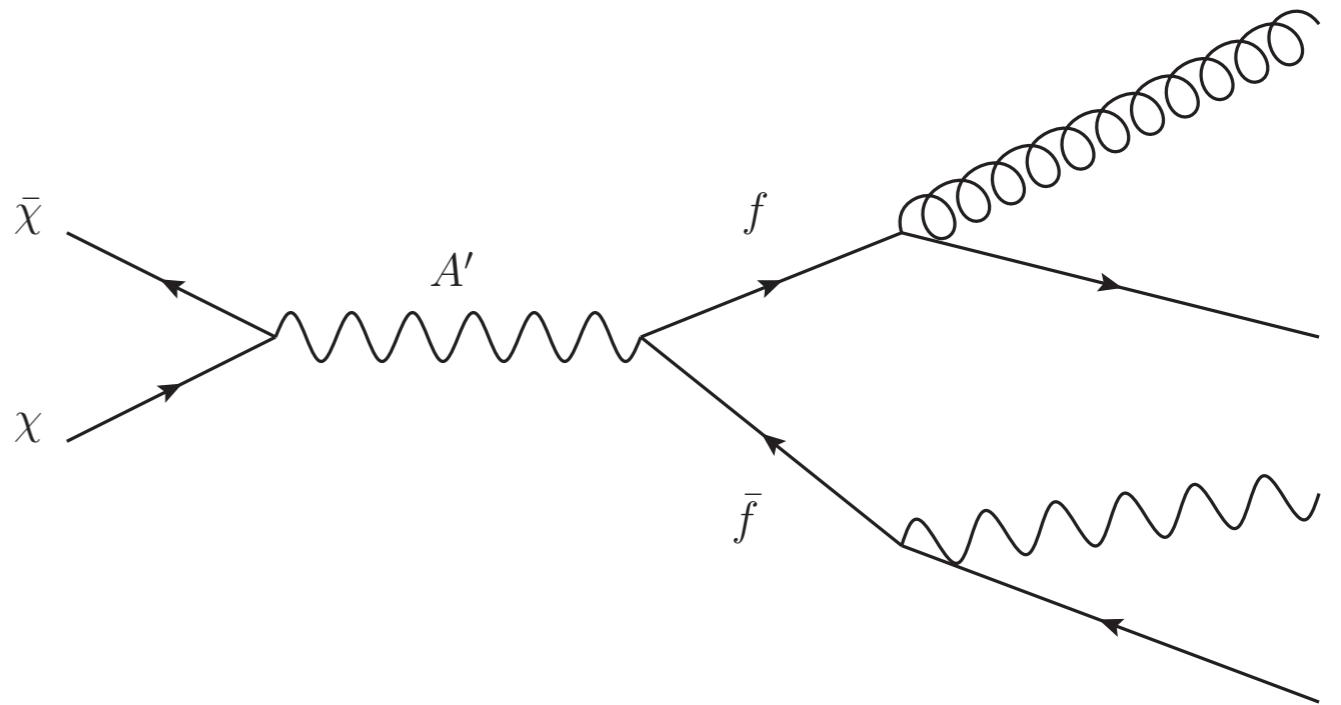


$L_\mu - L_\tau$ DM – future sensitivity

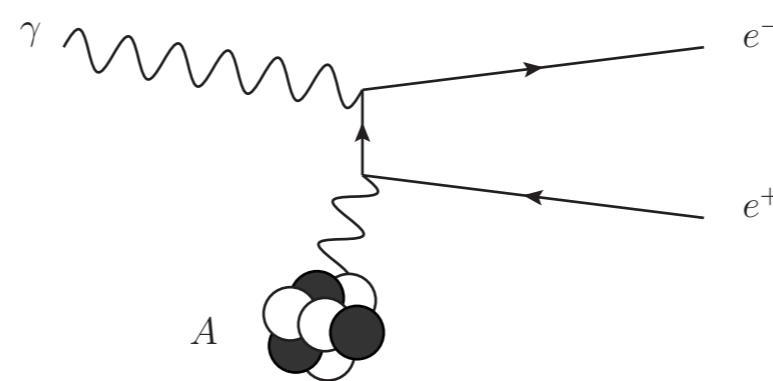
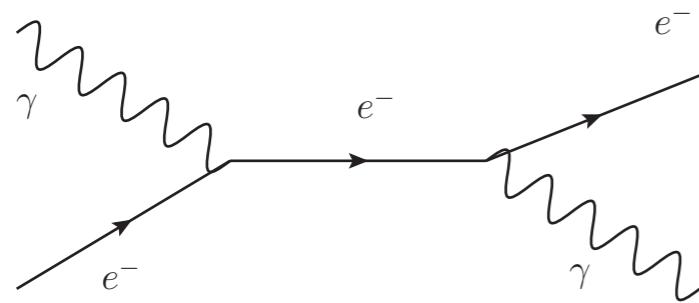


DM annihilation in the early Universe

- DM can inject energy into primordial plasma via cascade decays into secondary e^\pm , photons and neutrinos

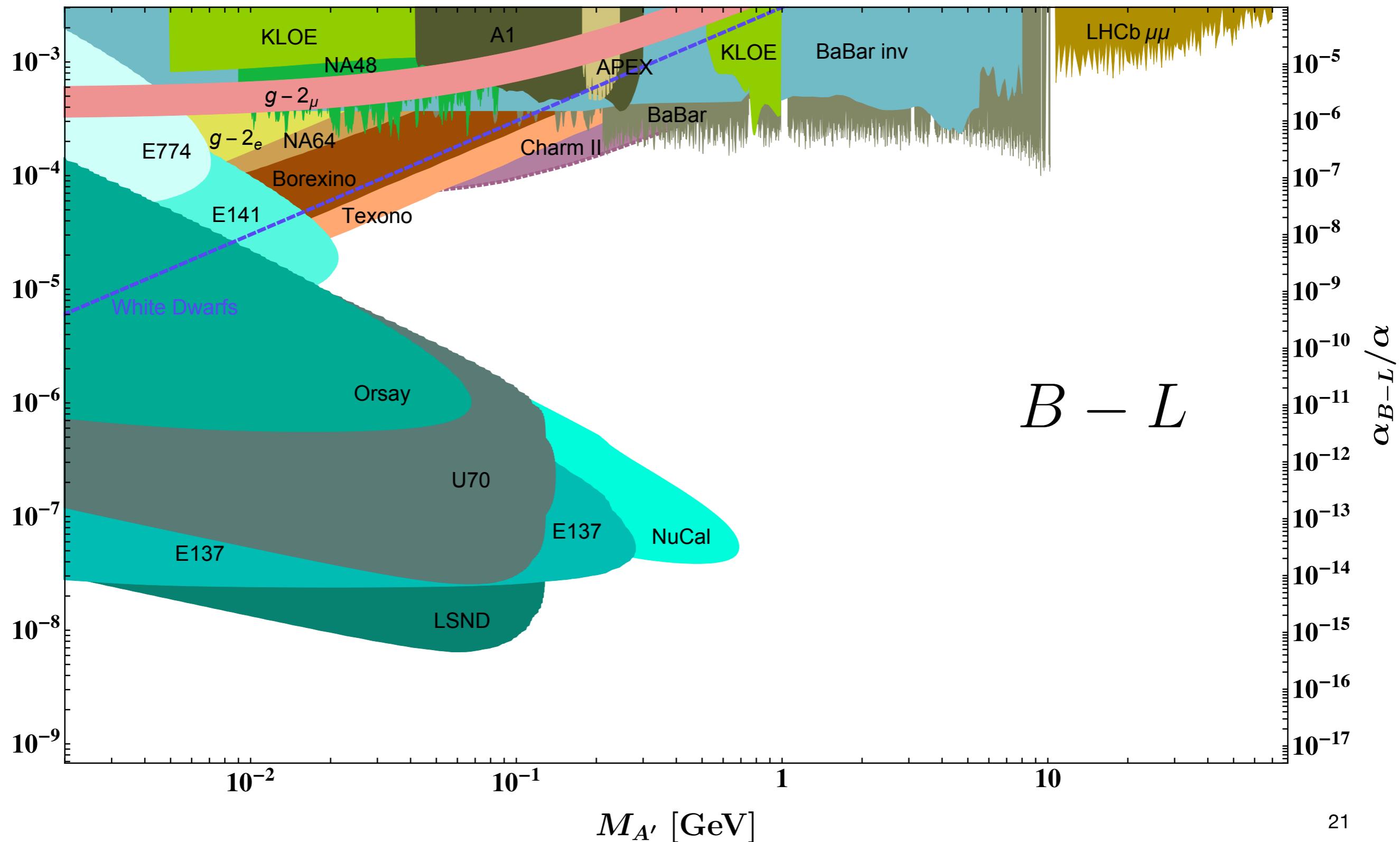


- Secondary particles heat and ionize IGM and alter post-recombination ionization fraction x_e of hydrogen



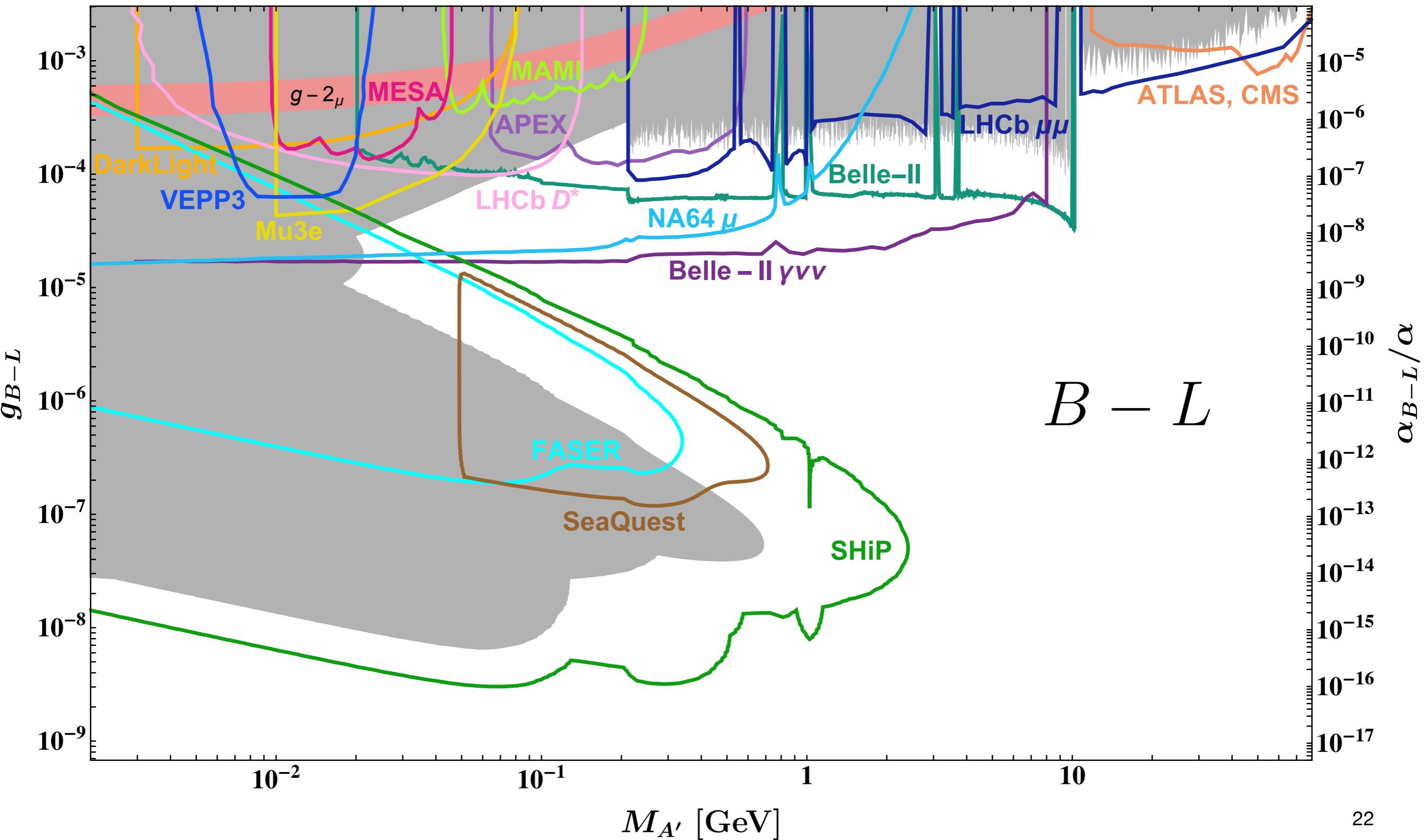
- Extra ionization leads to broadening of last scattering surface of CMB photons \rightarrow modification of TT, TE and EE power spectra

$B - L$ - current status

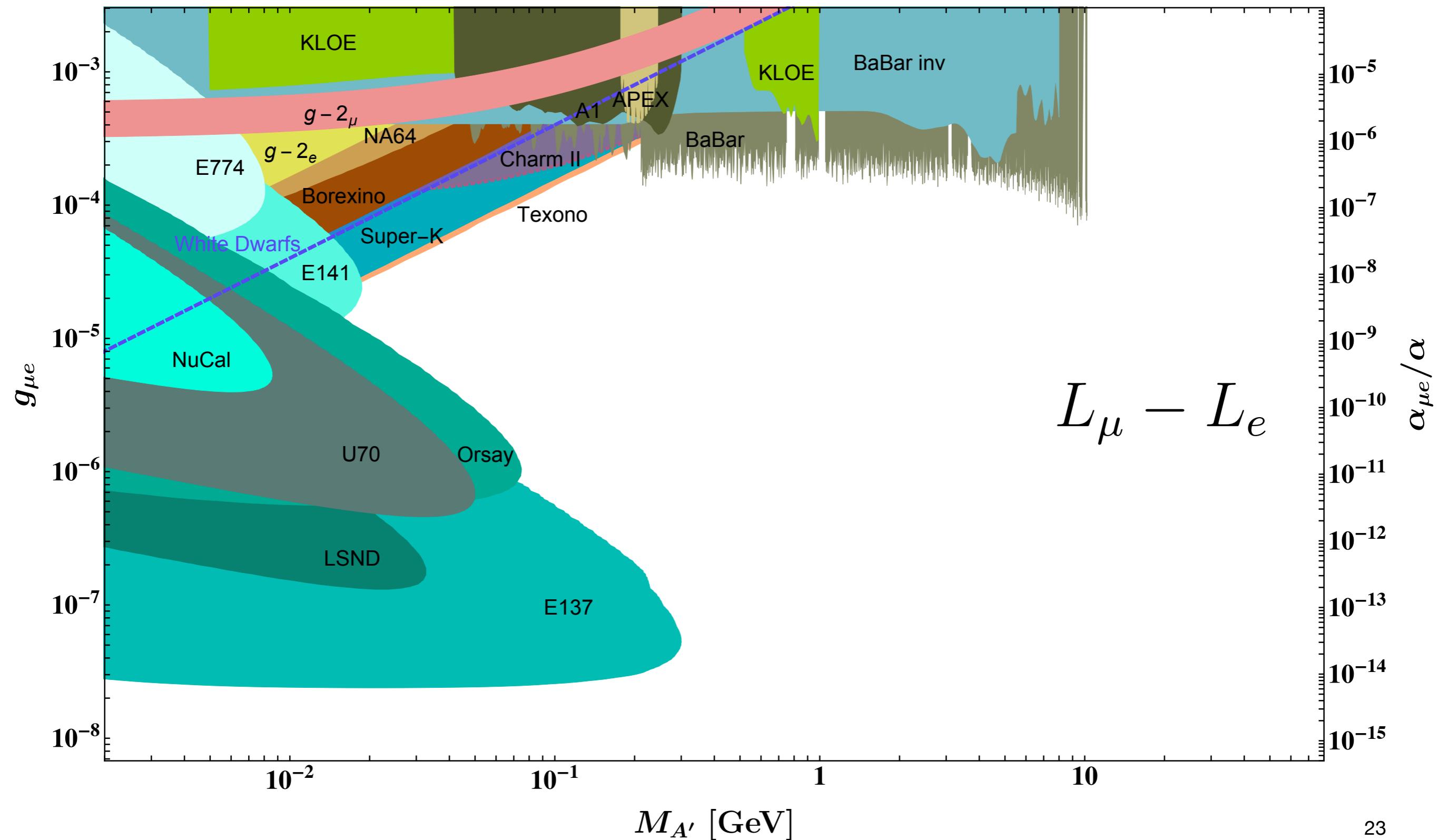


$B - L$

$B - L$ - future sensitivity

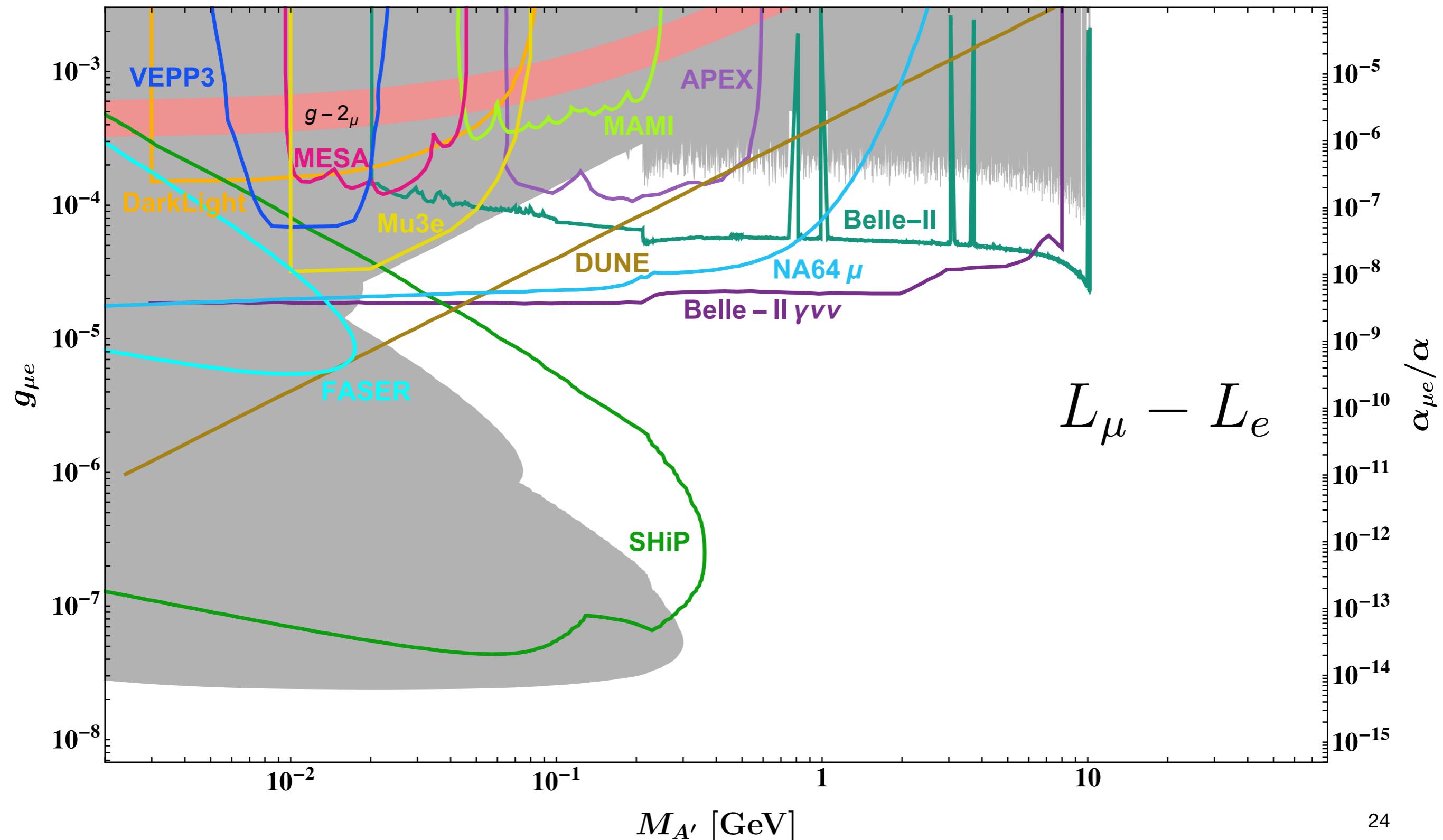


$L_\mu - L_e$ - current status

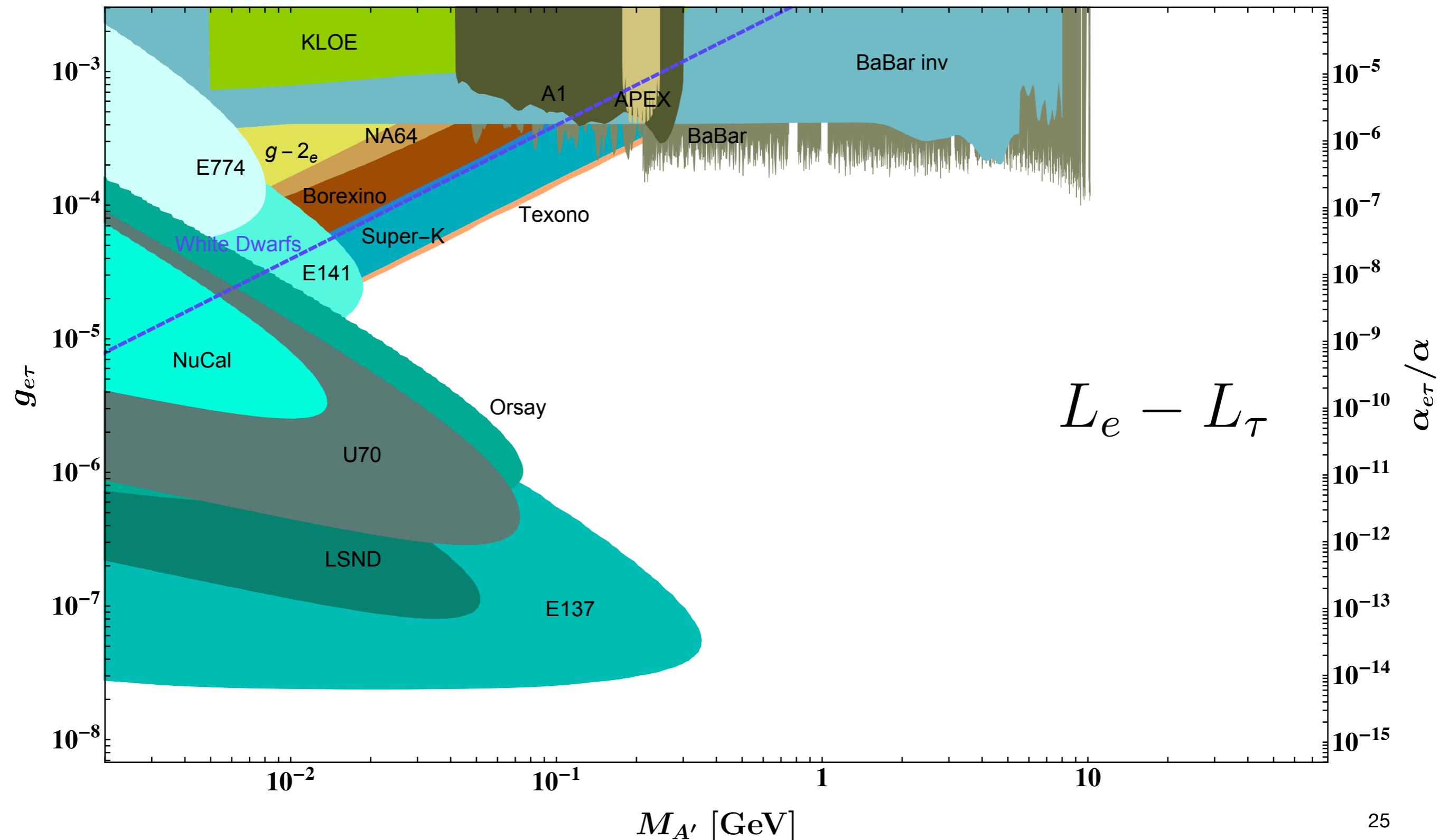


$L_\mu - L_e$

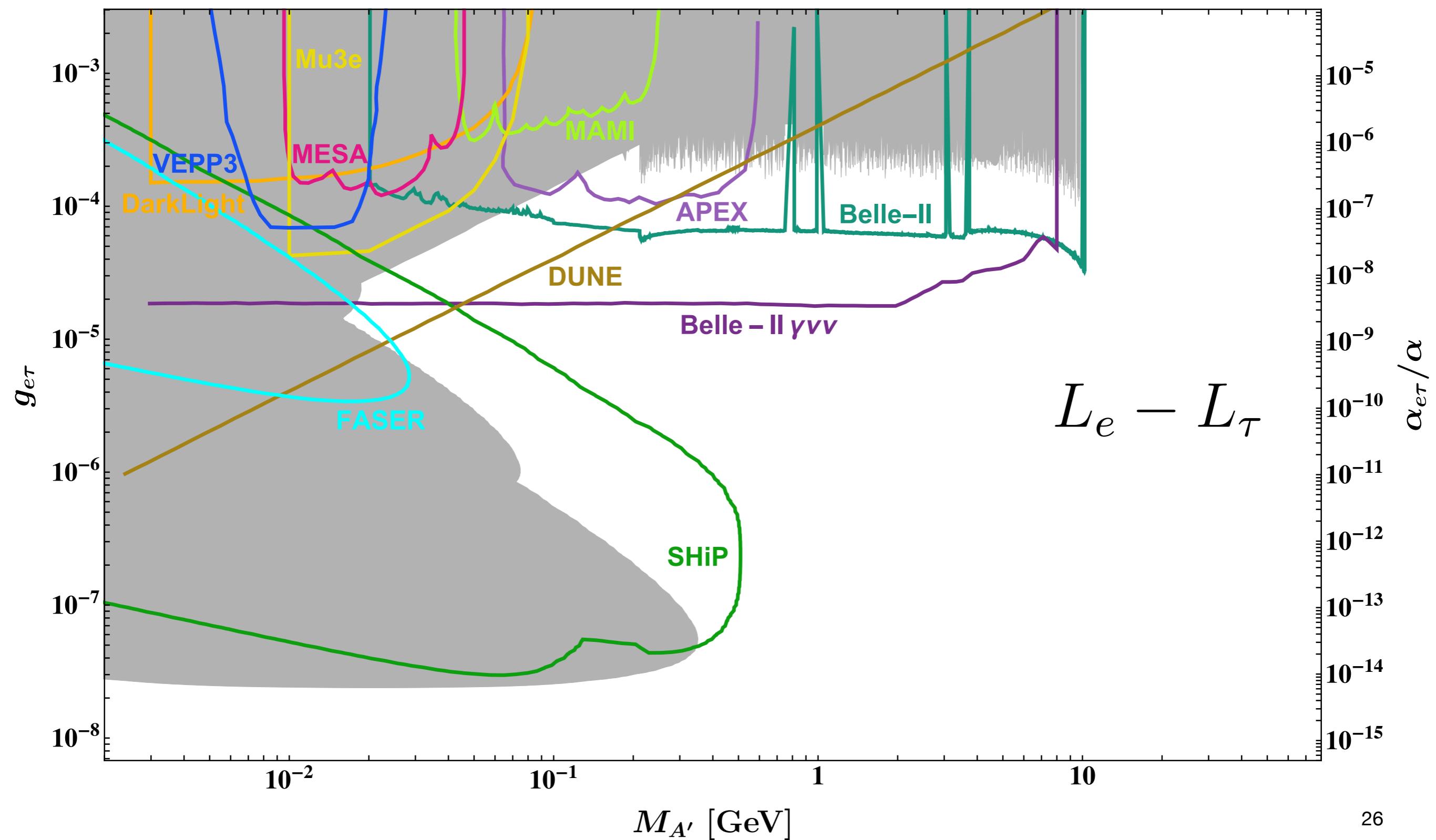
$L_\mu - L_e$ - future sensitivity



$L_e - L_\tau$ - current status

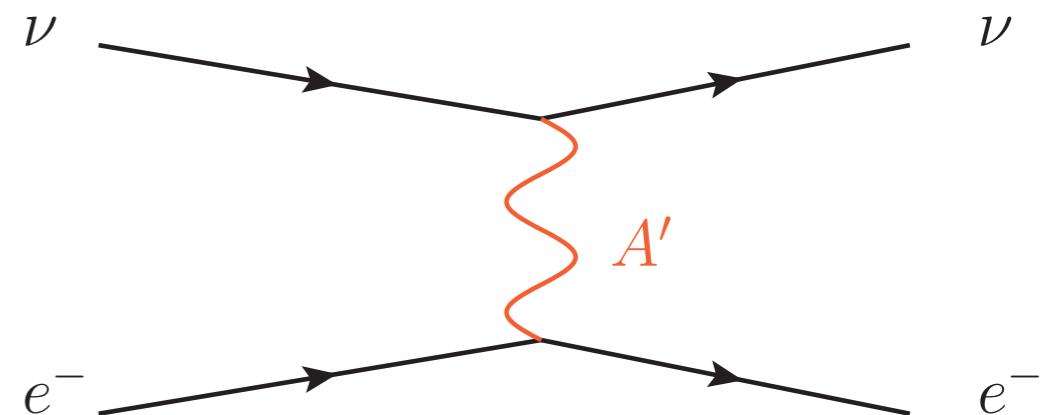


$L_e - L_\tau$ - future sensitivity



Neutrino experiments - Borexino

- Borexino has measured the elastic scattering rate of solar neutrinos off ${}^7\text{Be}$.



- Solar (electron) neutrinos oscillate on way to earth.
→ All neutrino flavors can contribute to scattering:

$$\frac{d\sigma}{dE} \propto \sum_{i,j=1}^3 f_i |g' (U^\dagger Q_\nu U)_{ij}|^2$$

with lepton mixing matrix U , neutrino charge matrix Q_ν , and the fraction f_i of the i -th neutrino mass eigenstate at earth.

Resonance searches

- E.g. at LHC A' can be produced in Drell-Yan.

- Number of signal events scales as

$$n_{\text{sig}} \propto \sigma_{\text{prod}} \times BR_{A' \rightarrow \ell\ell} \approx \frac{\epsilon^2}{M_{A'}^2} BR_{A' \rightarrow \ell\ell}$$

- Obtain upper limit n_{lim} from profile-likelihood of binned dilepton spectrum:

$$\Rightarrow n_{\text{sig}} \leq n_{\text{lim}} @ 90\% \text{C.L.}$$

