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# Light DM in a gauged $U(1)_{L_\mu - L_\tau}$

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Heidelberg University

based on

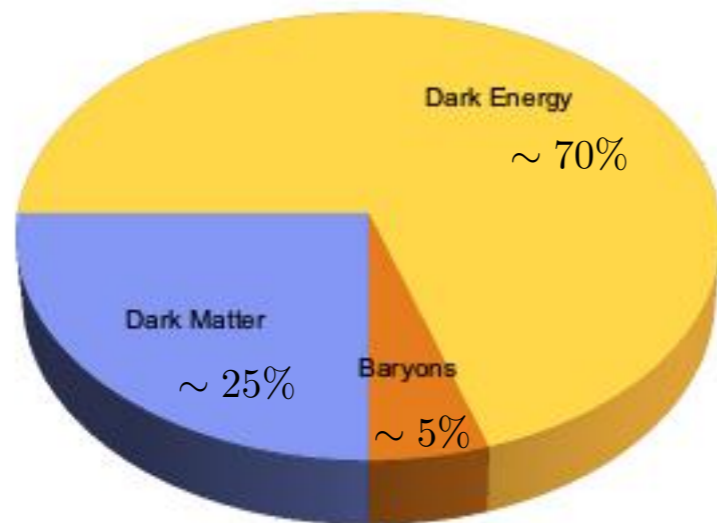
PF, [arXiv:1808.03647](https://arxiv.org/abs/1808.03647)  
Bauer, PF, Jaeckel, [arXiv:1803.05466](https://arxiv.org/abs/1803.05466)

Planck 2019, Granada — June 04

# Portals to New Physics

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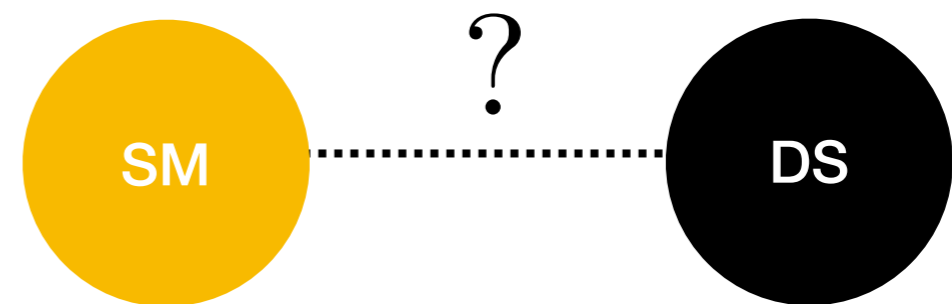
- Ample evidence for new physics, but internal dynamics unknown



# Portals to New Physics

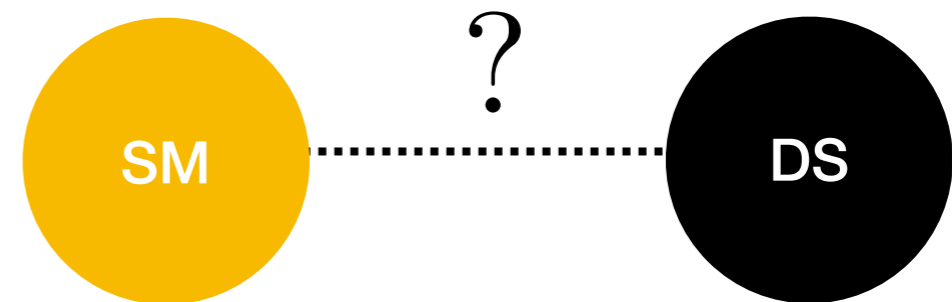
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- Ample evidence for new physics, but internal dynamics unknown



# Portals to New Physics

- Ample evidence for new physics, but internal dynamics unknown



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

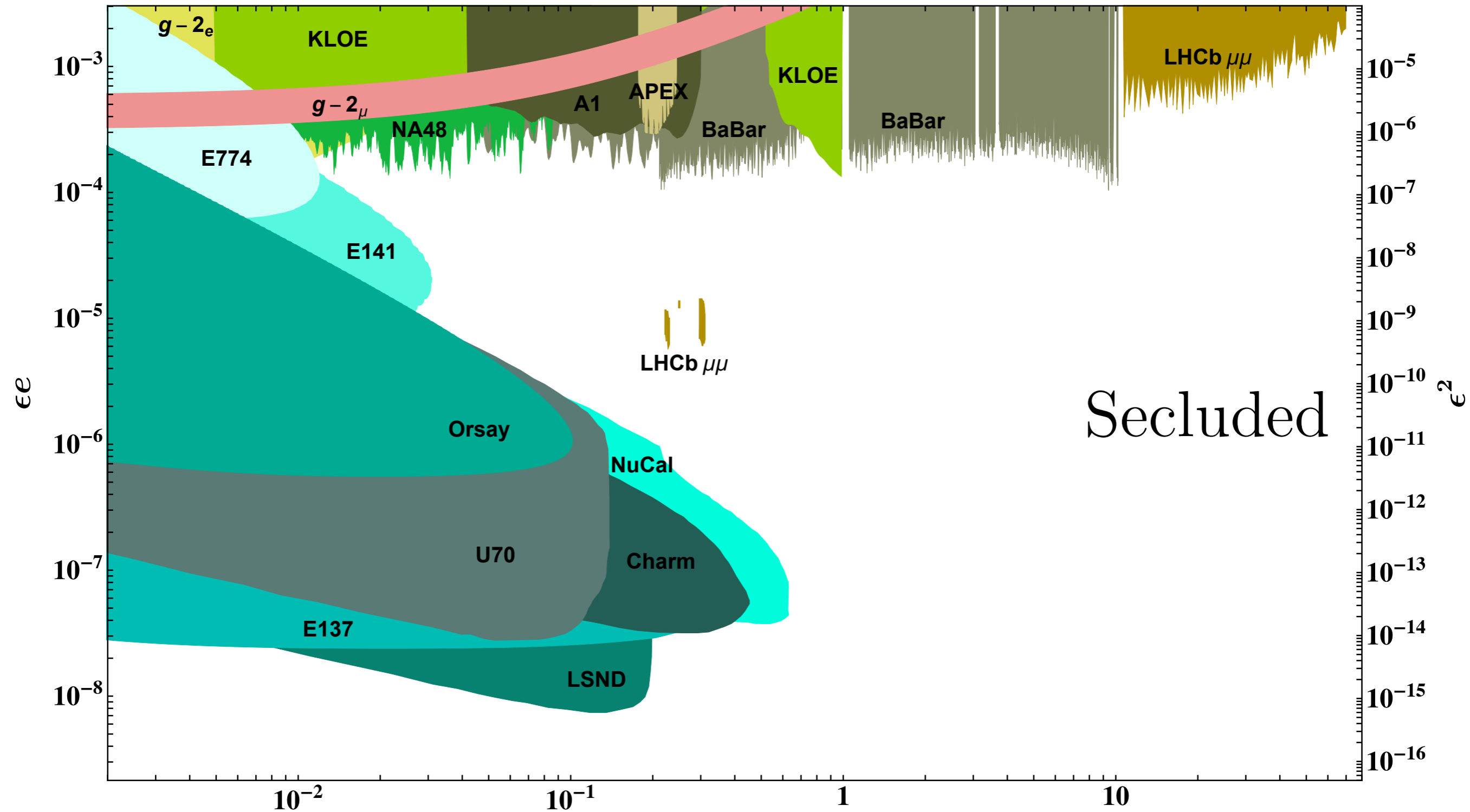
$$\mathcal{L}_{\text{kin}} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}F'_{\mu\nu}F'^{\mu\nu} - \frac{\epsilon}{2}F_{\mu\nu}F'^{\mu\nu}$$

[Holdom; PLB 166, 196]

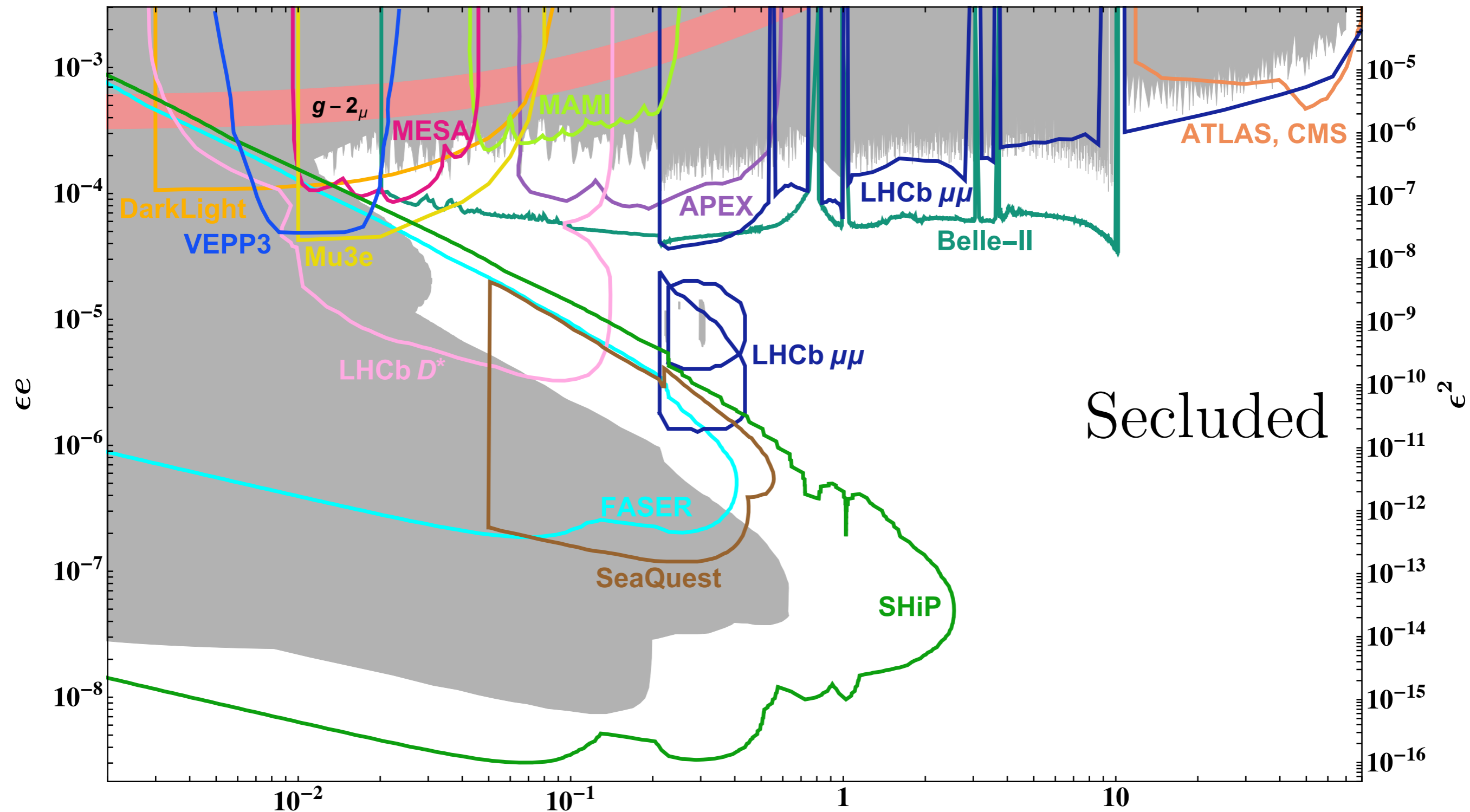
- Bringing kinetic terms into canonical form:

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

# Secluded $U(1)_X$ - current status



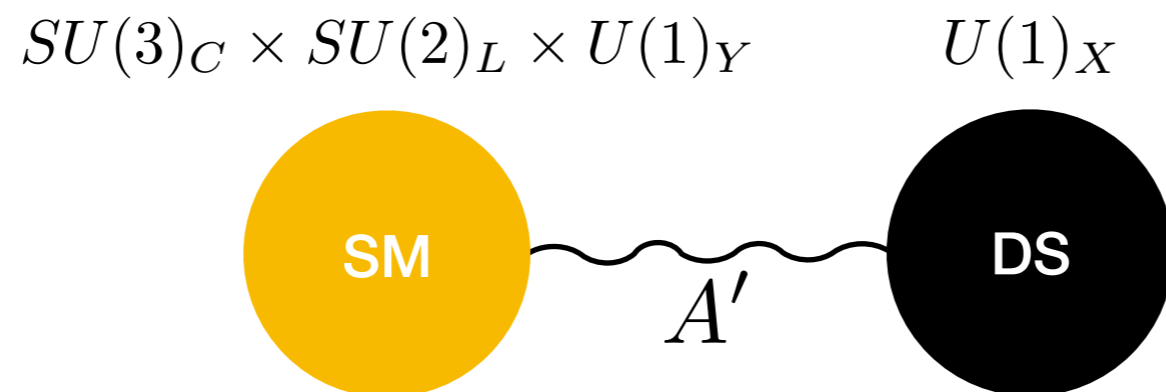
# Secluded $U(1)_X$ - future sensitivity



# Anomaly-free gauge groups

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Certain 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

**$L_\mu - L_e$**

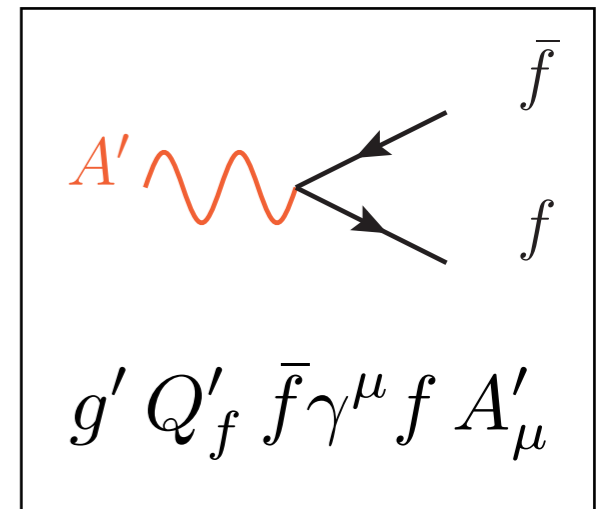
charging 1st &  
2nd generation  
leptons

**$L_e - L_\tau$**

charging 1st &  
3rd generation  
leptons

**$L_\mu - L_\tau$**

charging 2nd &  
3rd generation  
leptons





# Charging SM fields under extra U(1)

- Four extra anomaly-free groups within the SM:

**B - L**

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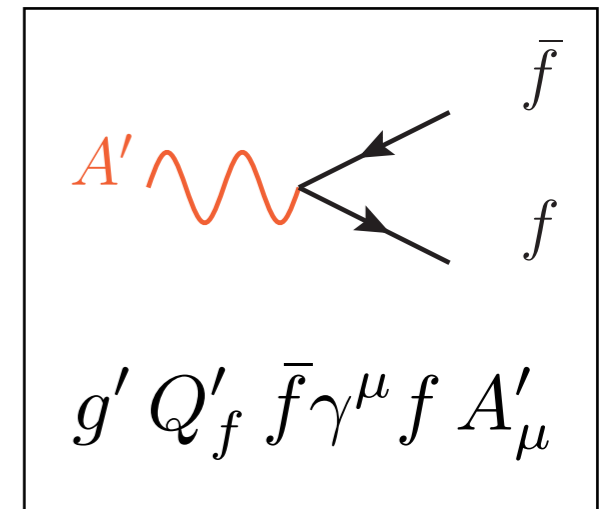
charging 1st &  
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leptons

**$L_e - L_\tau$**

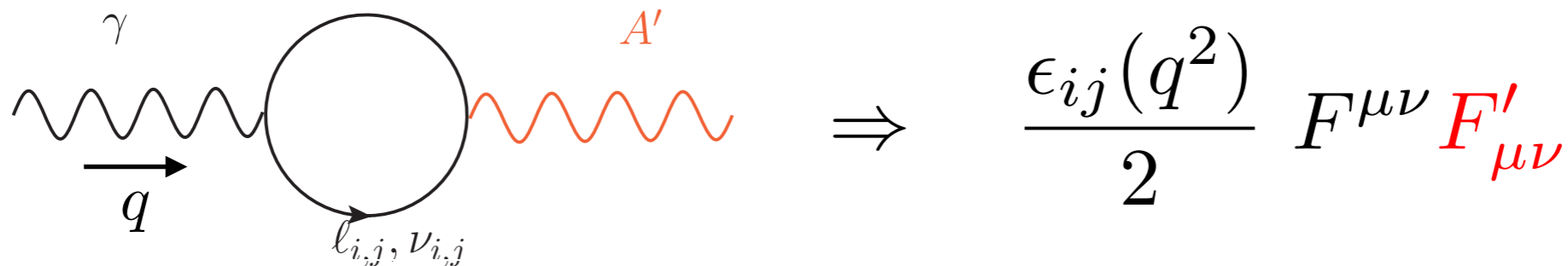
charging 1st &  
3rd generation  
leptons

**$L_\mu - L_\tau$**

charging 2nd &  
3rd generation  
leptons



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



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

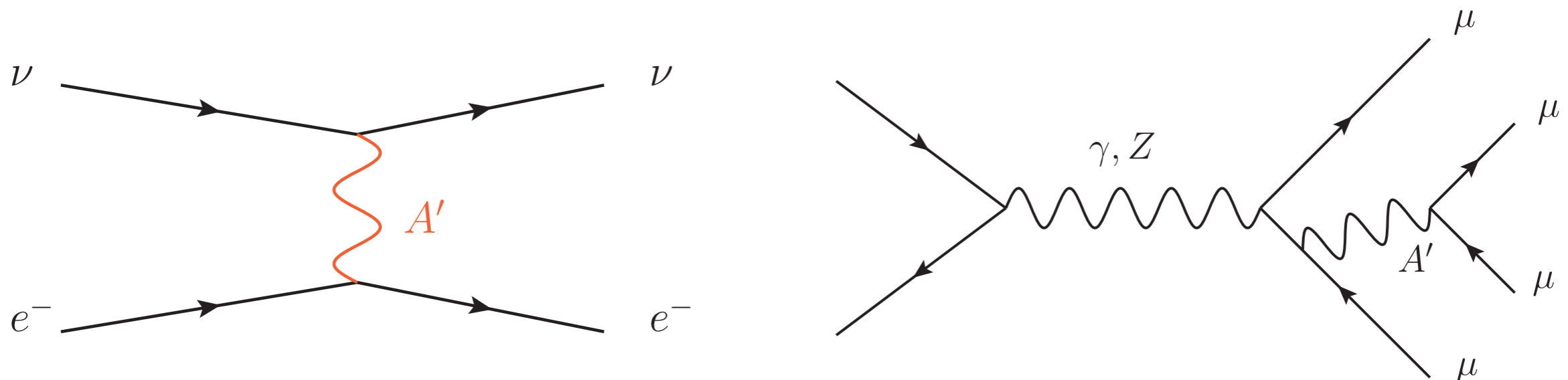
# Example: searches for $U(1)_{L_\mu - L_\tau}$

$$J_{\mu\tau}^\alpha = \bar{L}_2 \gamma^\alpha L_2 + \bar{\mu}_R \gamma^\alpha \mu_R - \bar{L}_3 \gamma^\alpha L_3 - \bar{\tau}_R \gamma^\alpha \tau_R$$

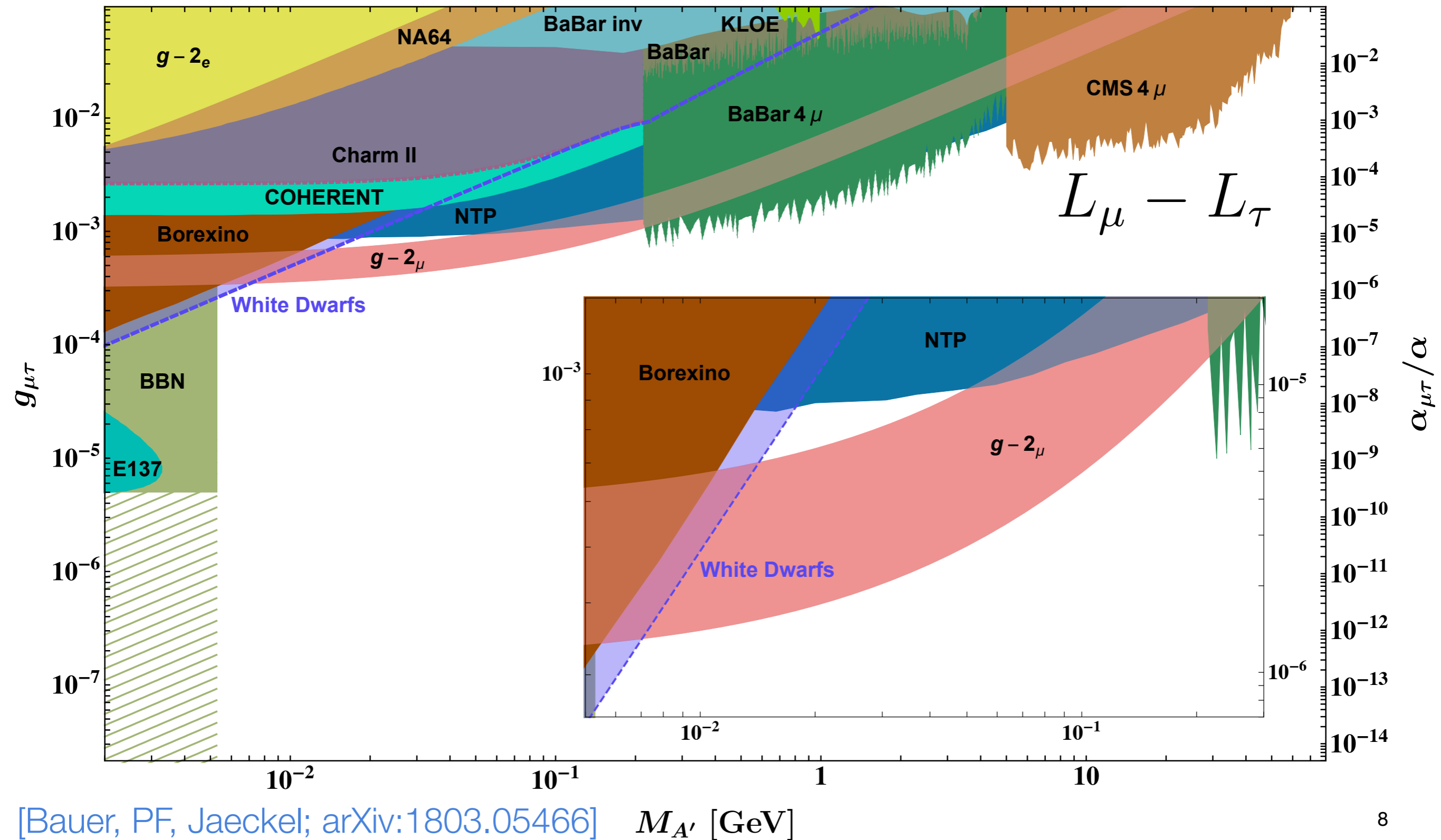
- Large **coupling hierarchy** of loop-induced kinetic mixing to gauge coupling:

$$\frac{\epsilon_{\mu\tau} e}{g_{\mu\tau}} \propto \frac{6\alpha}{\pi} \log\left(\frac{m_\tau}{m_\mu}\right) \approx \mathcal{O}(10^{-2})$$

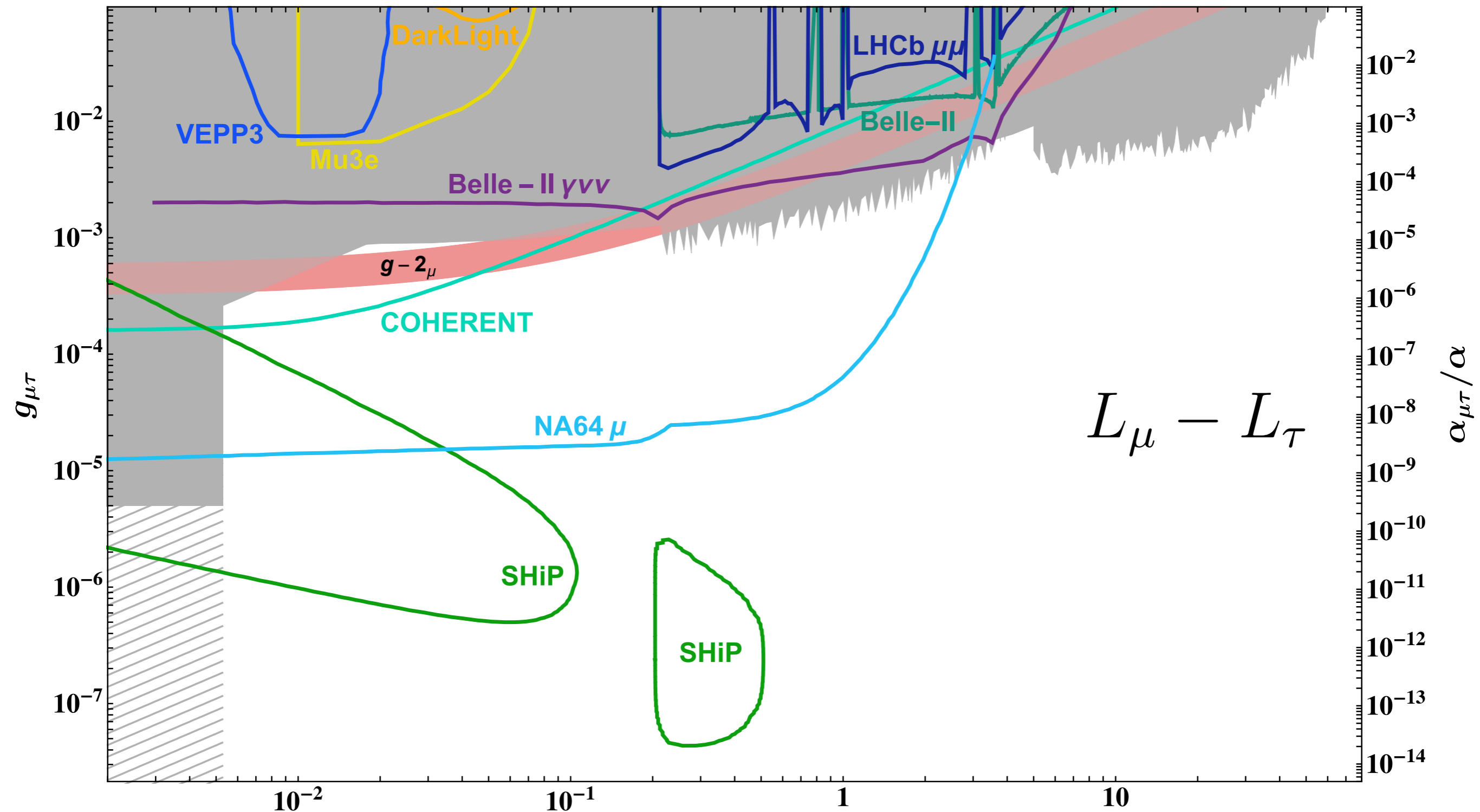
- Couplings to electrons and hadrons strongly suppressed  
**→ Typical collider and beam dump searches become insensitive**
- **Neutrinos** and **muons** become important!



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



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



# Fermionic $L_\mu - L_\tau$ DM

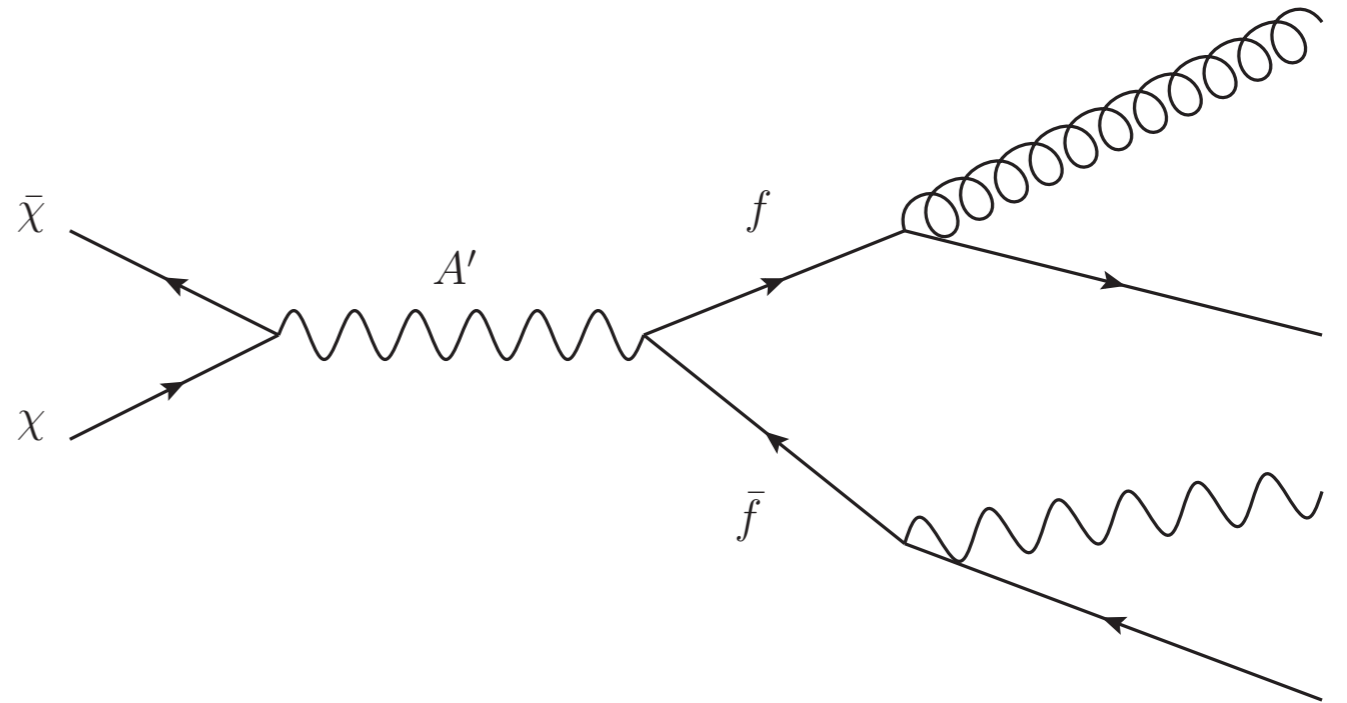
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Augment field content by light vector-like fermion charged under  $U(1)_{L_\mu - L_\tau}$ .

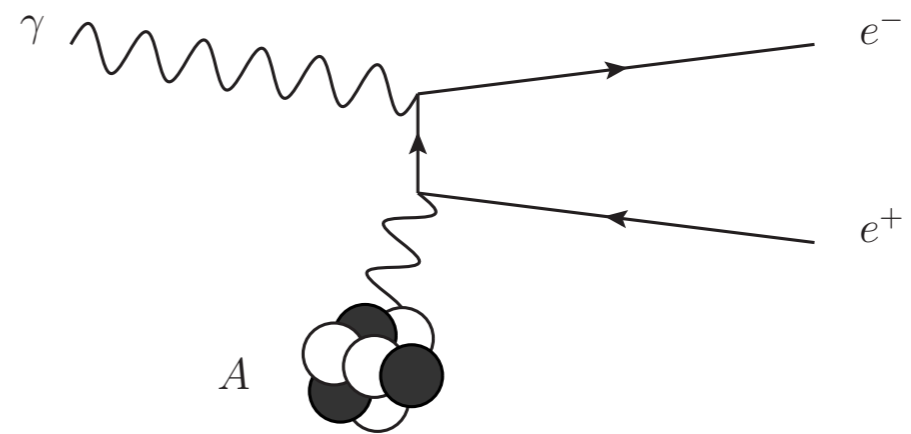
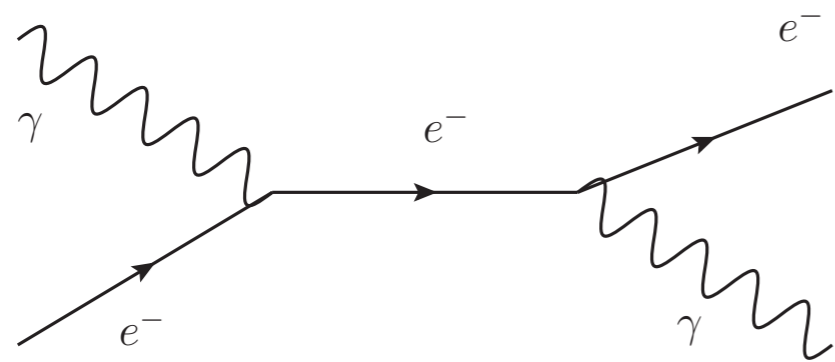
$$\mathcal{L} = -g_{\mu\tau} Q_\chi \bar{\chi} \gamma^\mu \chi A'_\mu - m_\chi \bar{\chi} \chi$$

# DM annihilation in the early Universe

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

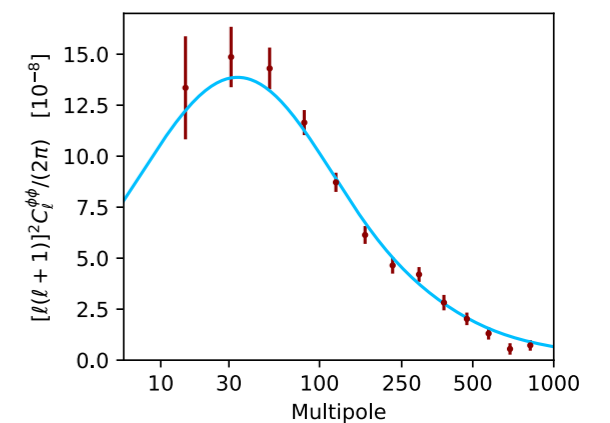
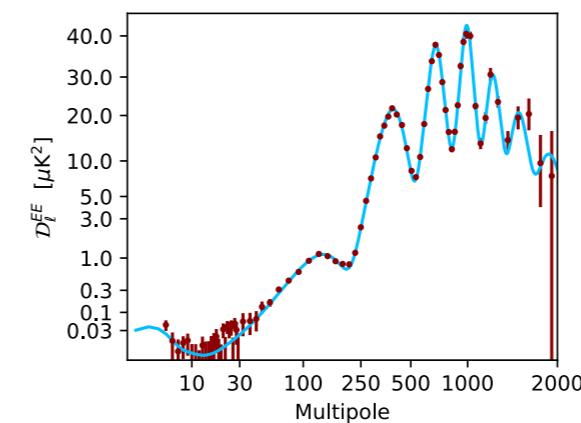
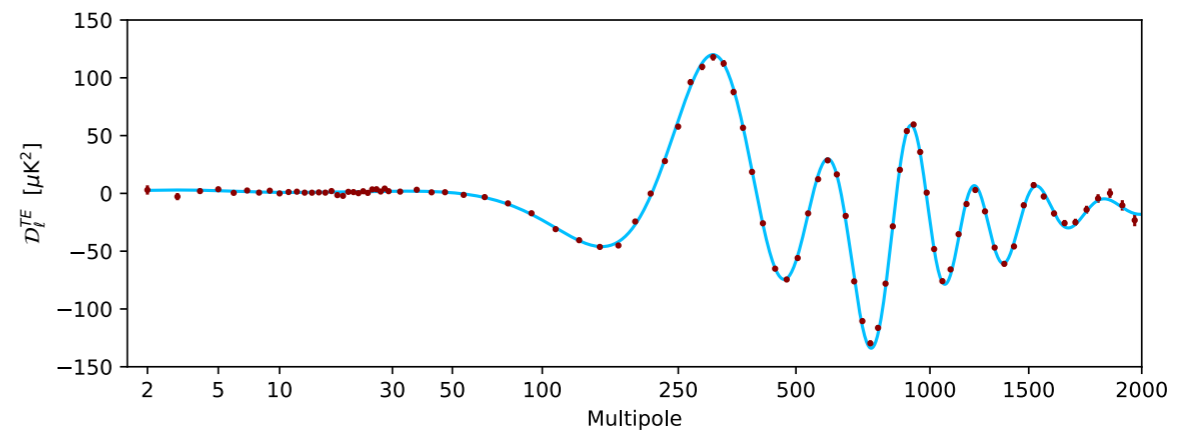
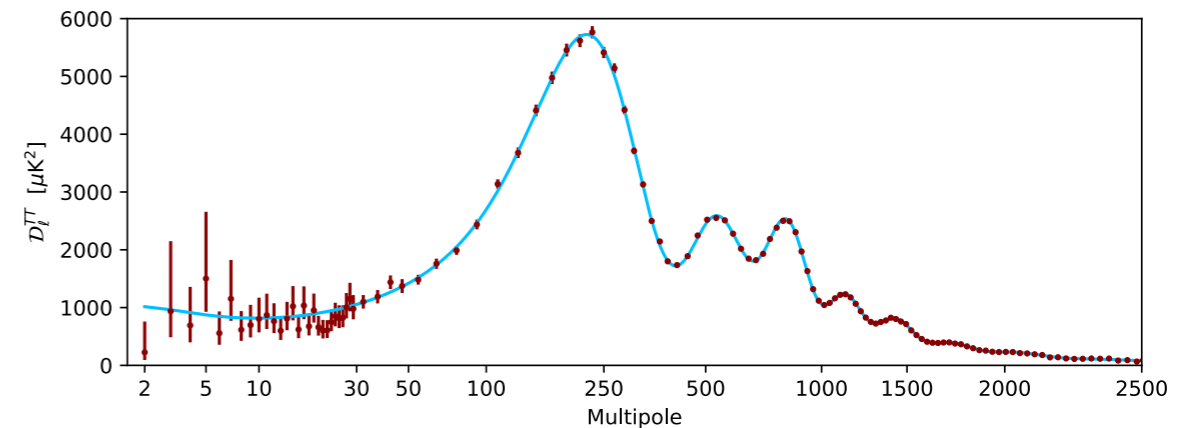
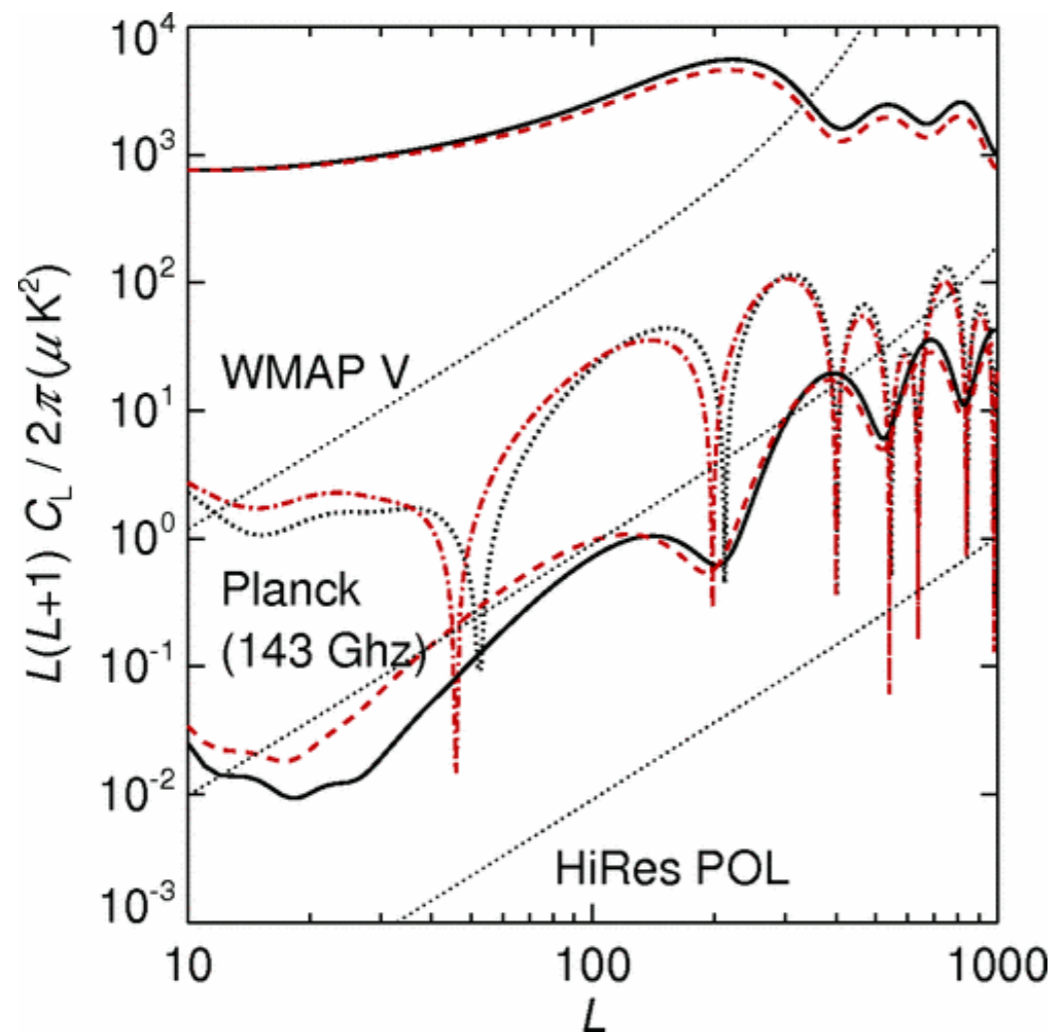


- Secondary particles heat and ionize IGM and alter post-recombination ionization fraction  $x_e$  of hydrogen



# DM annihilation in the early Universe

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



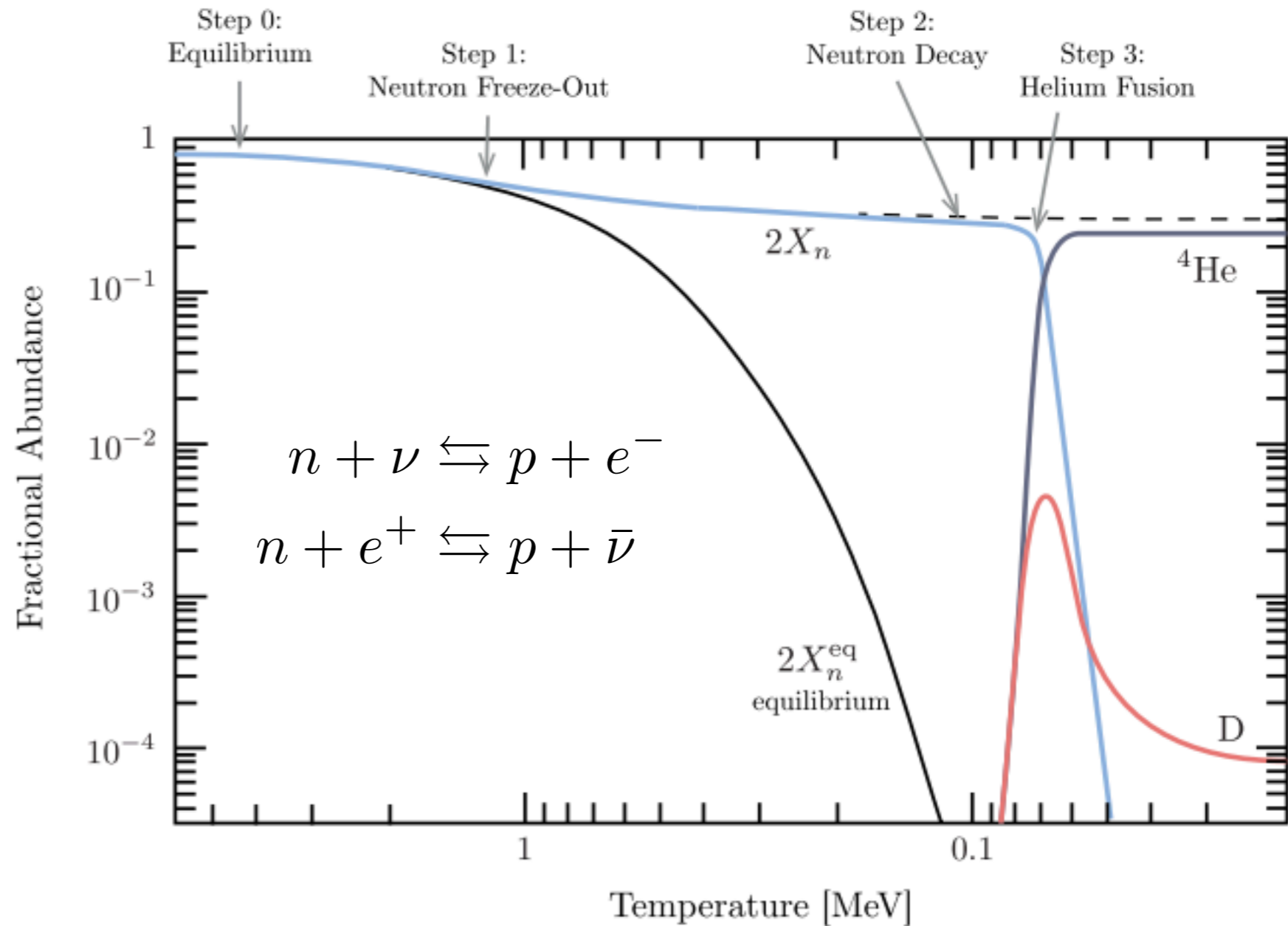
[Padmanabahn, Finkbeiner; astro-ph/0503486]

- Precise Planck measurement puts strong constraint on  $\langle \sigma v \rangle$  @  $T_{\text{CMB}}$

[Planck; 1807.06209]

# $N_{\text{eff}}$ @ BBN

- Freeze-out of weak interactions determines primordial neutron concentration  $X_n$  in early universe
- Freeze-out happens when  $\Gamma \approx H$

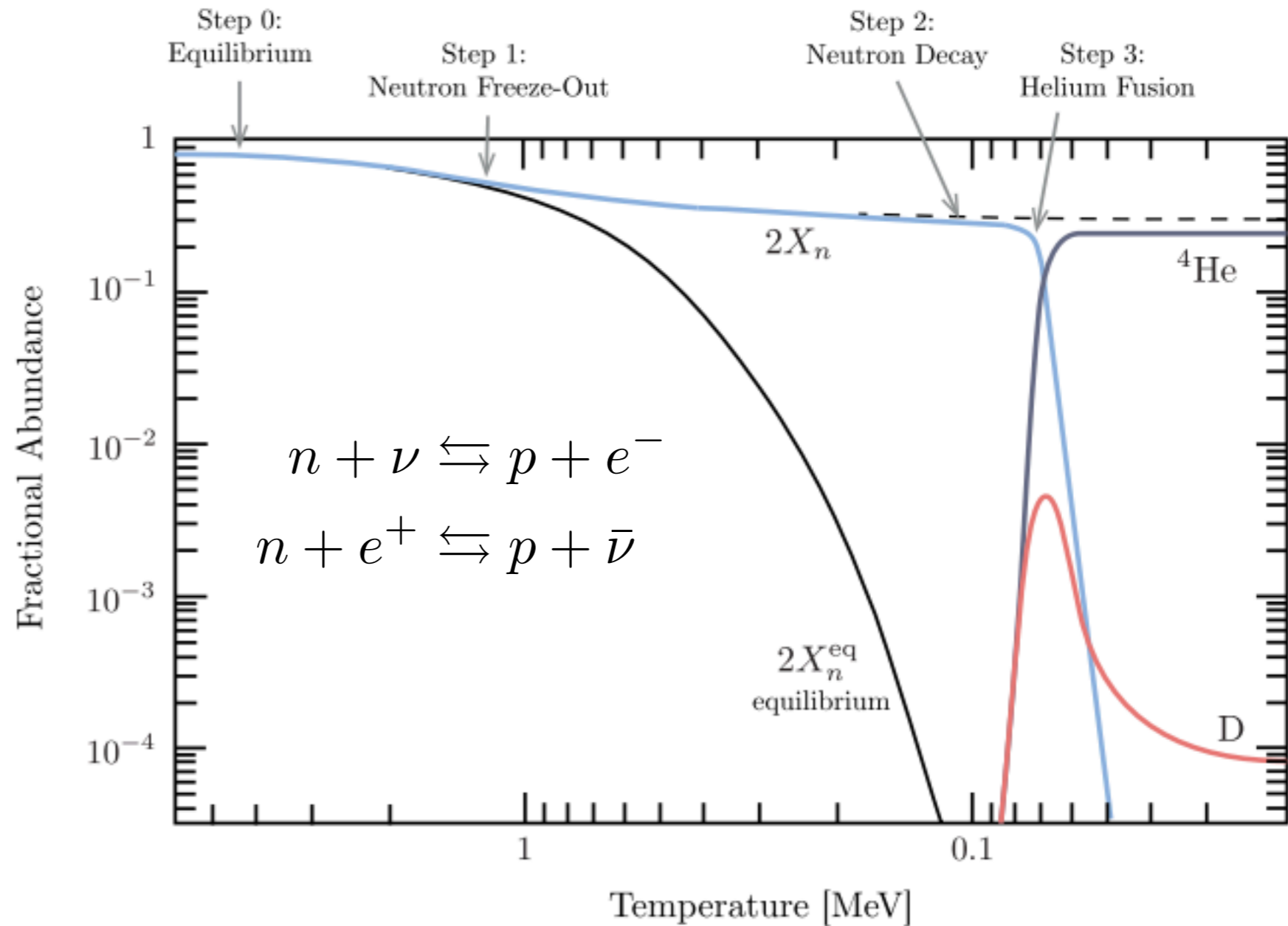


[Baumann, *Cosmology - Part III*]



# $N_{\text{eff}}$ @ BBN

- Freeze-out of weak interactions determines primordial neutron concentration  $X_n$  in early universe
- Freeze-out happens when  $\Gamma \approx H$
- In radiation domination era



[Baumann, *Cosmology - Part III*]

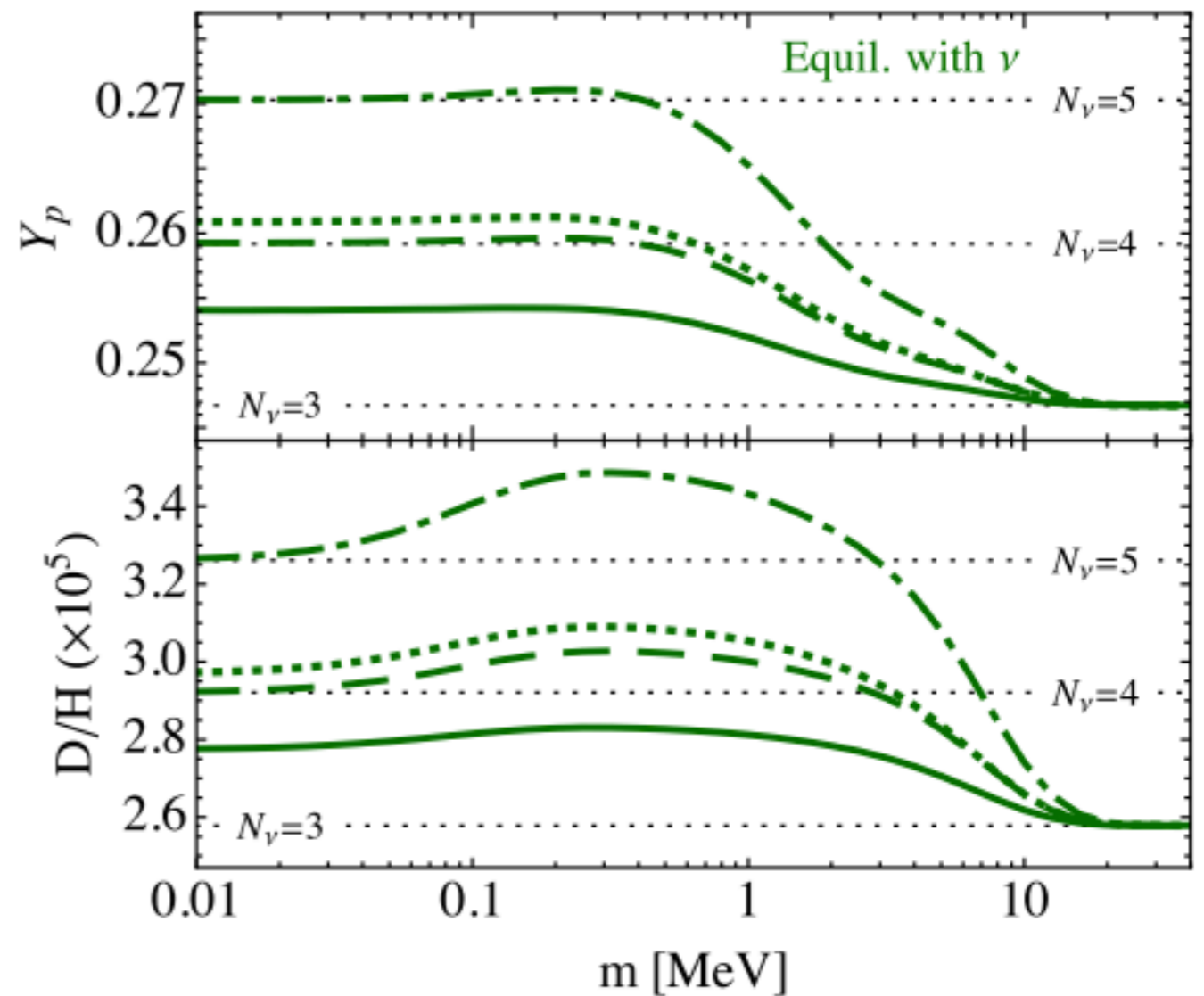
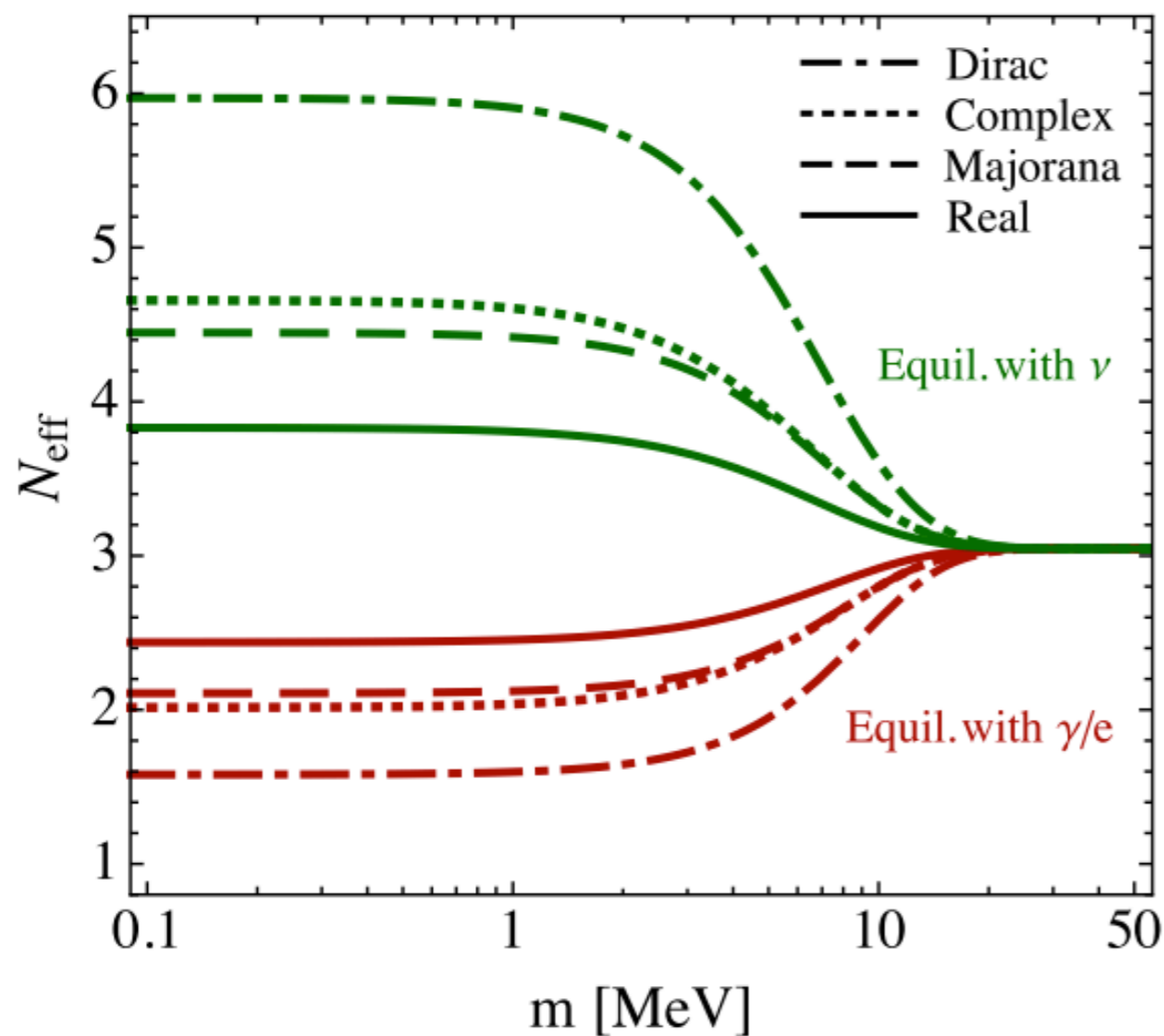
$$H^2 = \frac{8\pi}{3M_{\text{Pl}}^2} \rho_R$$

$$\rho_R = \rho_\gamma \left[ 1 + \frac{7}{8} \left( \frac{T_\nu^0}{T_\gamma} \right) N_{\text{eff}} \right]$$

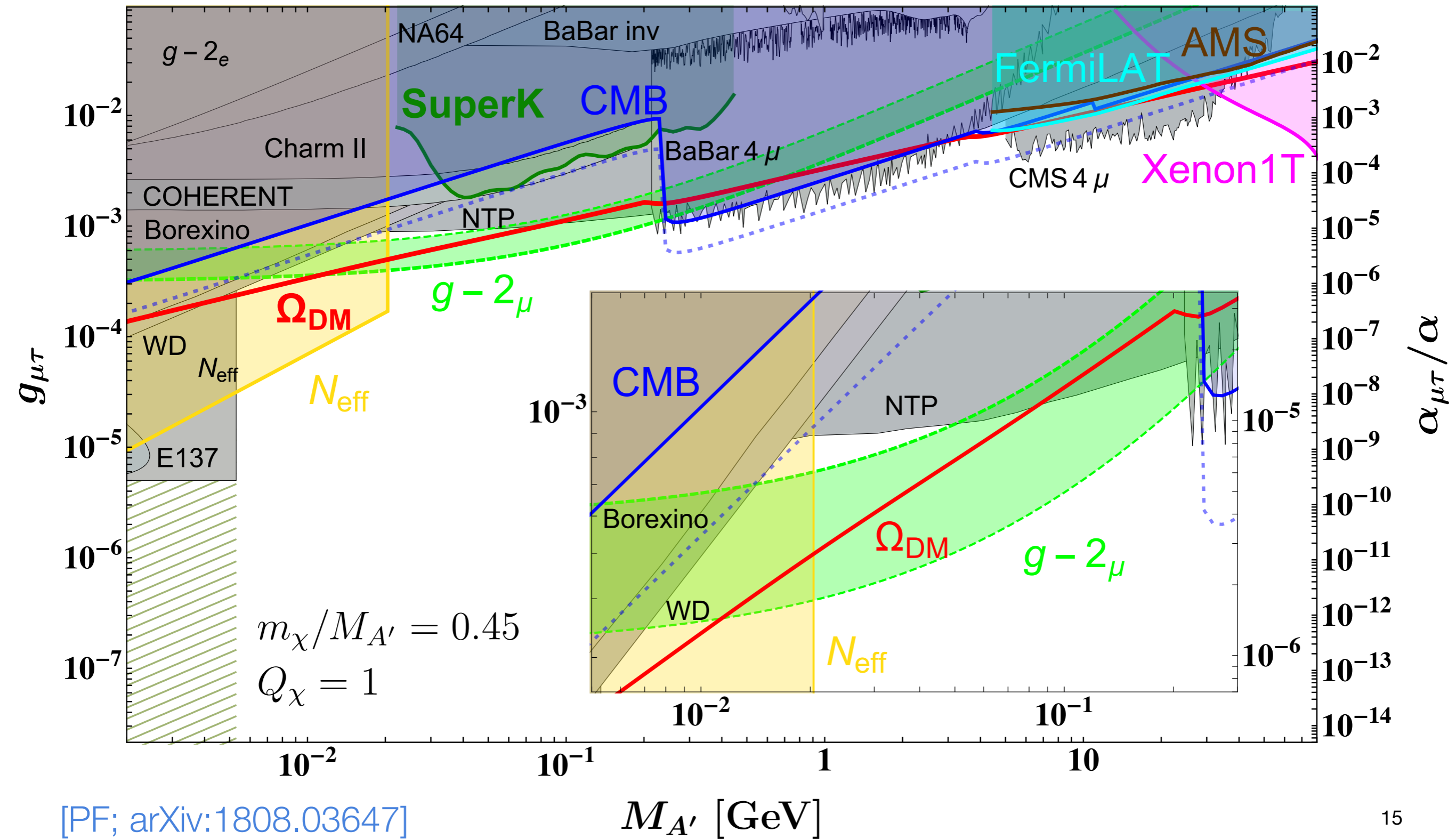
# $N_{\text{eff}}$ @ BBN

DM in equilibrium with neutrinos transfers entropy to  $\nu$ 's once it becomes non-rel at  $T \sim m_\chi$  and reheats neutrino gas

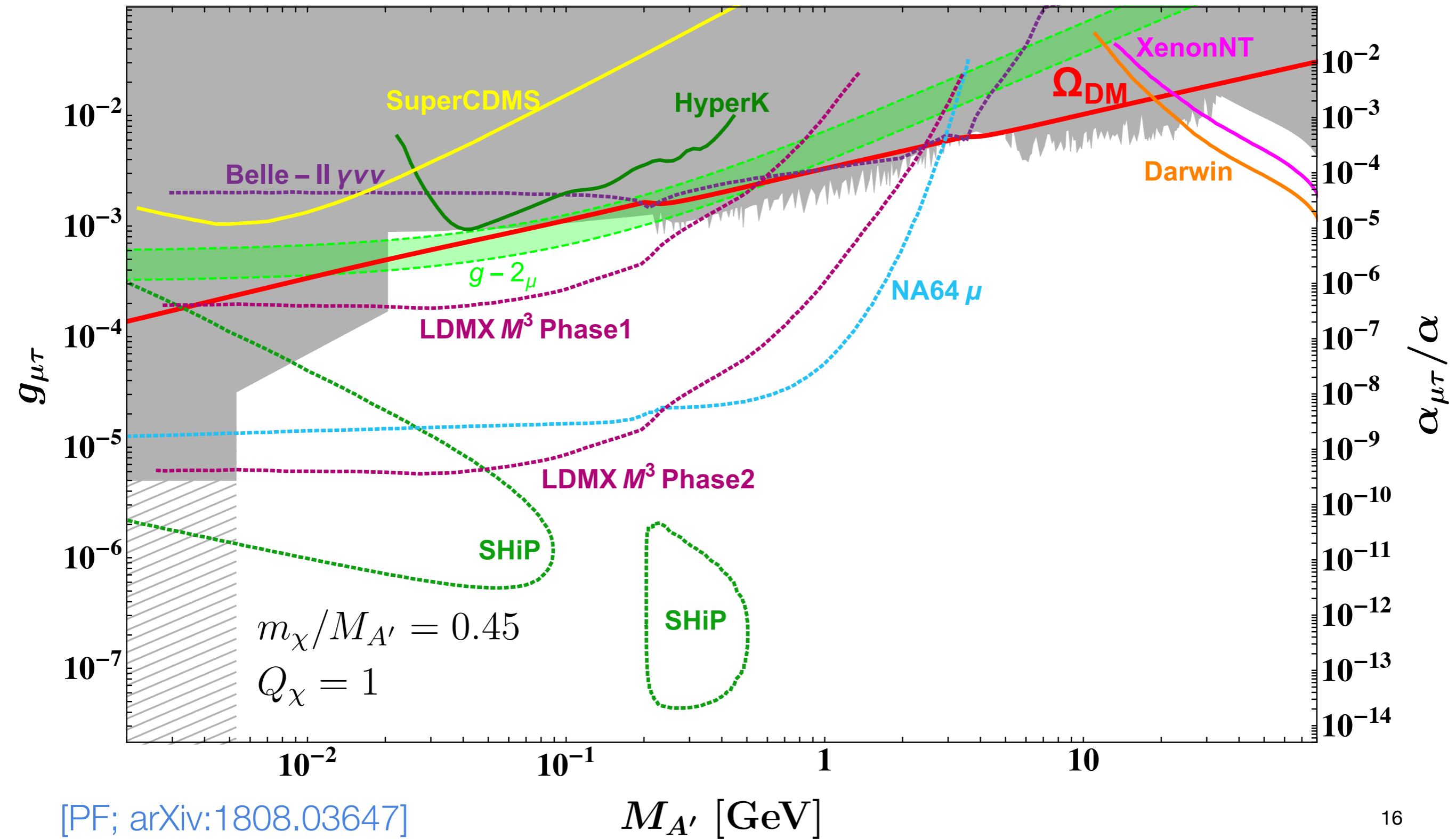
➔ increase of  $N_{\text{eff}}$



# $L_\mu - L_\tau$ DM – Near Resonance



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



# Conclusions

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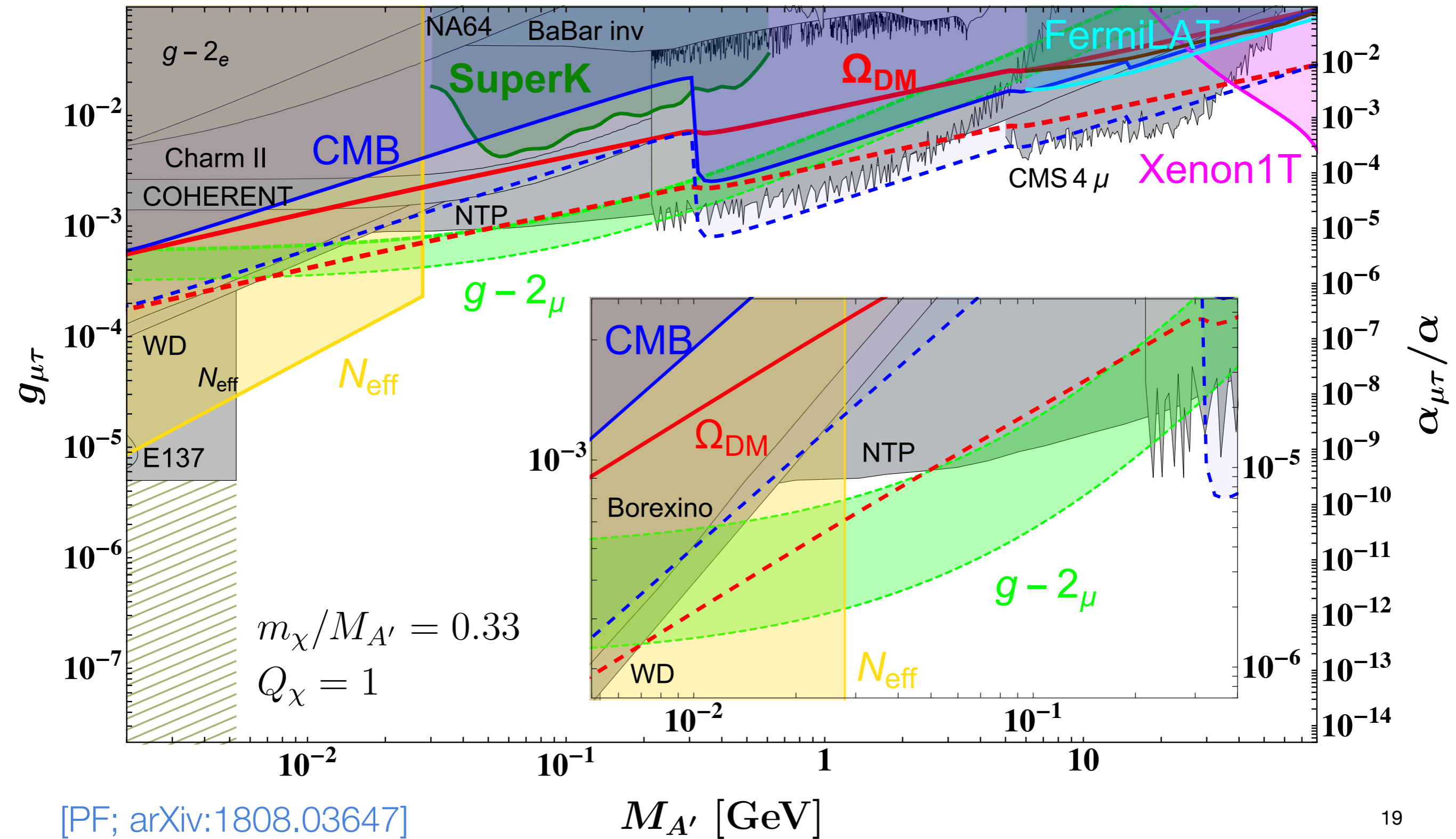
- Portal models are consistent way to incorporate NP into the SM.
- Gauge couplings to SM particles can **dramatically reshape** the landscape of **HP constraints**.  
→ Need to use full complementarity of experimental searches!
- **Simultaneous explanation** of  $(g - 2)_\mu$  and  $\Omega_{\text{DM}}$  in extended  $U(1)_{L_\mu - L_\tau}$ .
- Future experiments like **LDMX**, **SHiP** and a dedicated **muon run of NA64** can rule out large part of  $U(1)_{L_\mu - L_\tau}$  parameter space.

Thank you for your attention!

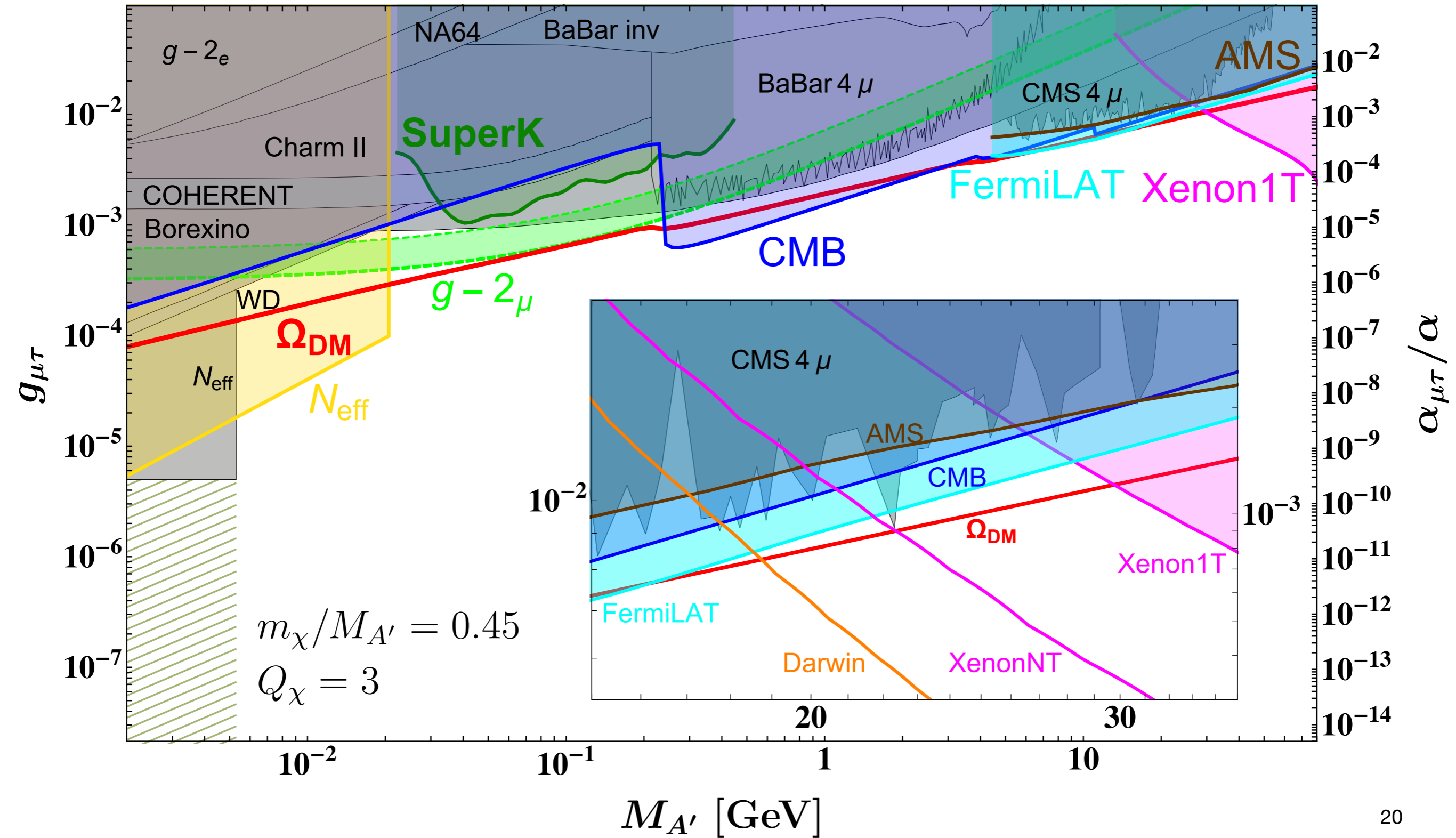
# Backup

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



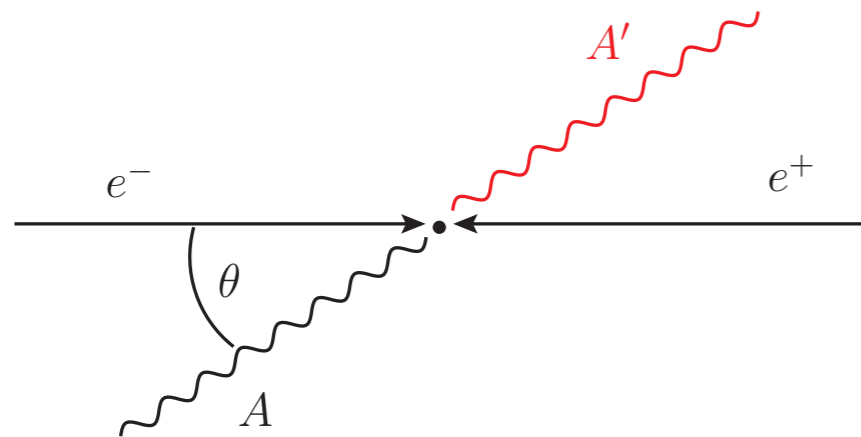
# $L_\mu - L_\tau$ DM – Non-unit charge



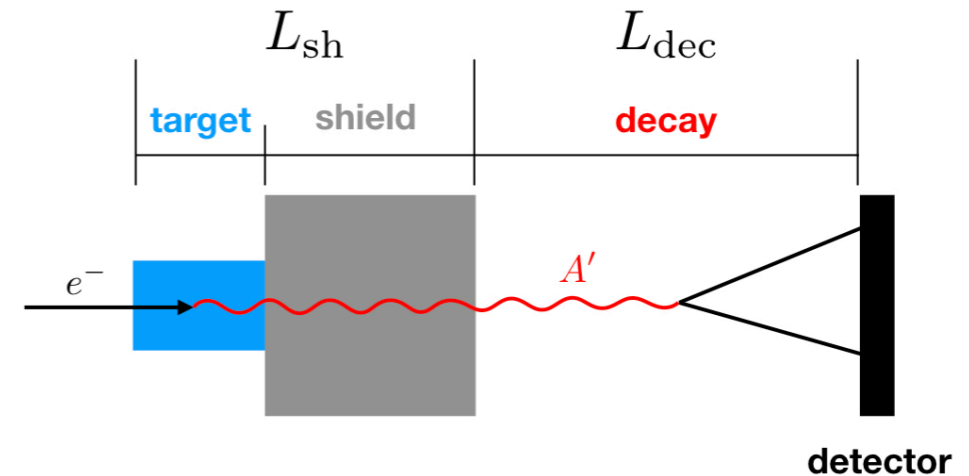


# Prototypical Hidden Photon Searches

Colliders:

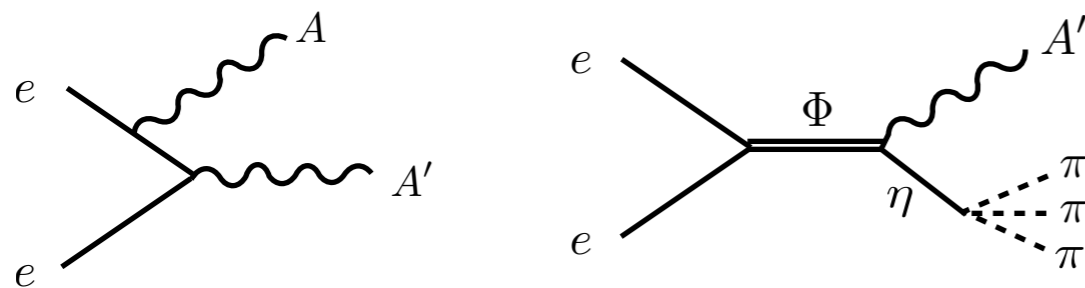


Beam dumps:



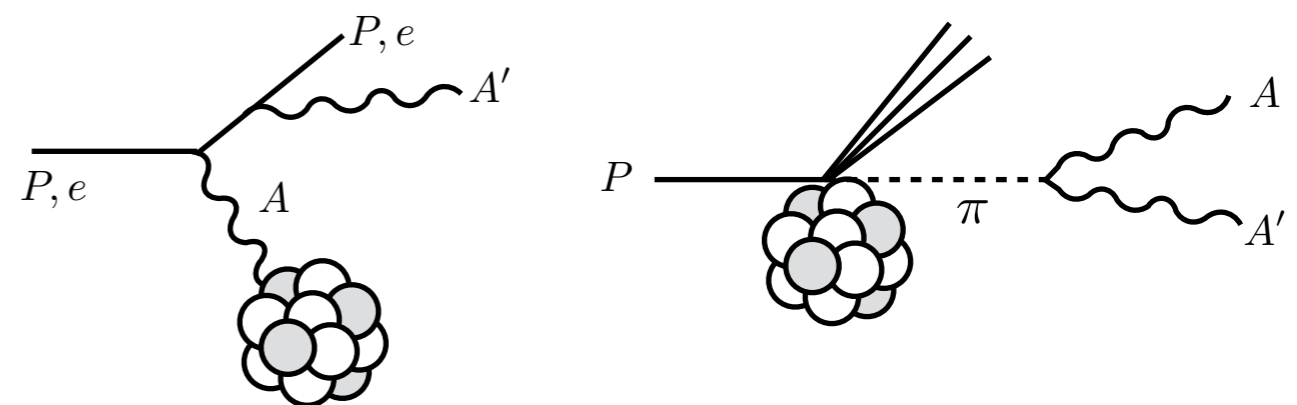
$$P_{\text{dec}} = e^{-\frac{L_{\text{sh}}}{\ell_{A'}}} \left( 1 - e^{-\frac{L_{\text{dec}}}{\ell_{A'}}} \right)$$

• Production:



$$\mathcal{L}^{\text{coll}} \approx \mathcal{O}(10^{-1}) \text{ ab}^{-1} \text{ yr}^{-1}$$

$$\sigma_{A'}^{\text{coll}} \propto \frac{\alpha^2 \epsilon^2}{E_{\text{CM}}^2}$$



$$\mathcal{L}^{\text{coll}} \approx \mathcal{O}(1) \text{ ab}^{-1} \text{ d}^{-1}$$

$$\sigma_{A'}^{\text{bd}} \propto \frac{\alpha^3 Z^2 \epsilon^2}{M_{A'}^2}$$