Status of Light Dark Matter Searches at Accelerators

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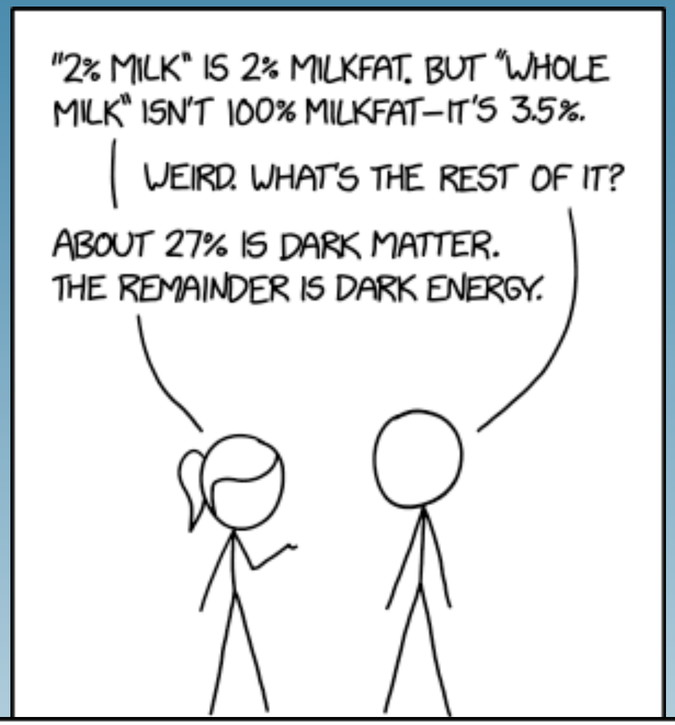
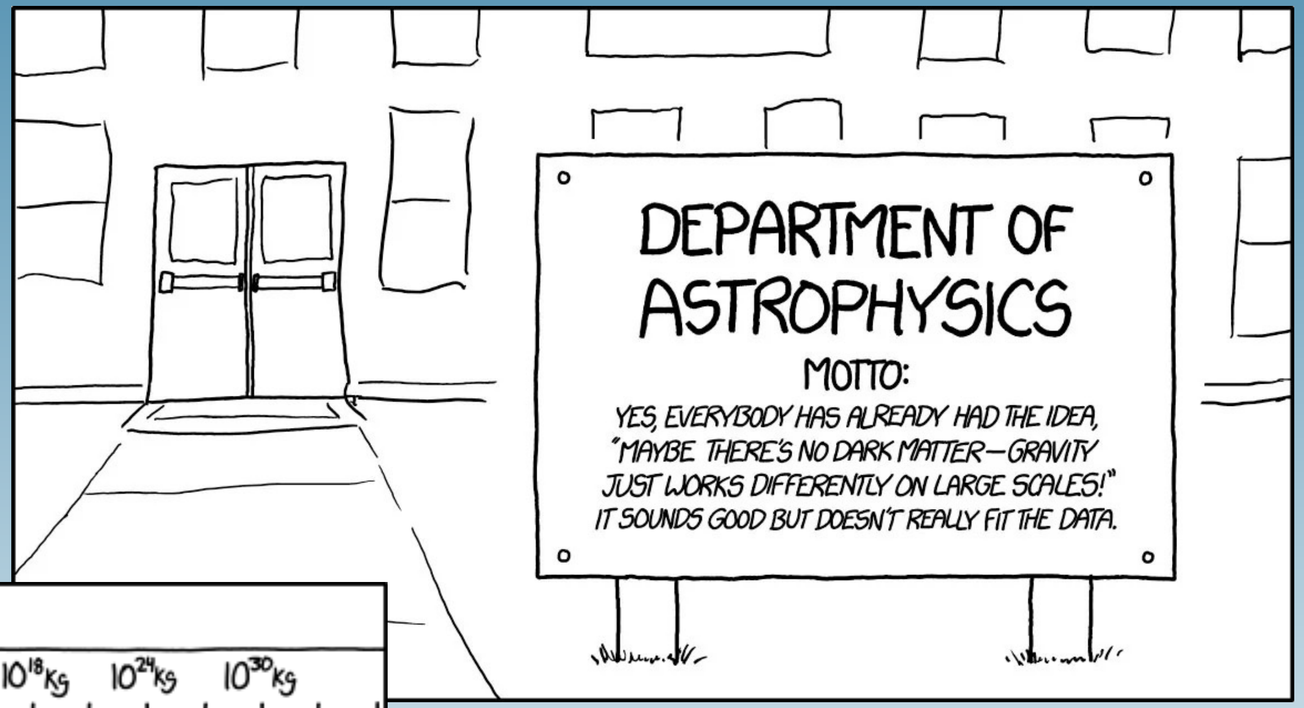
Outline

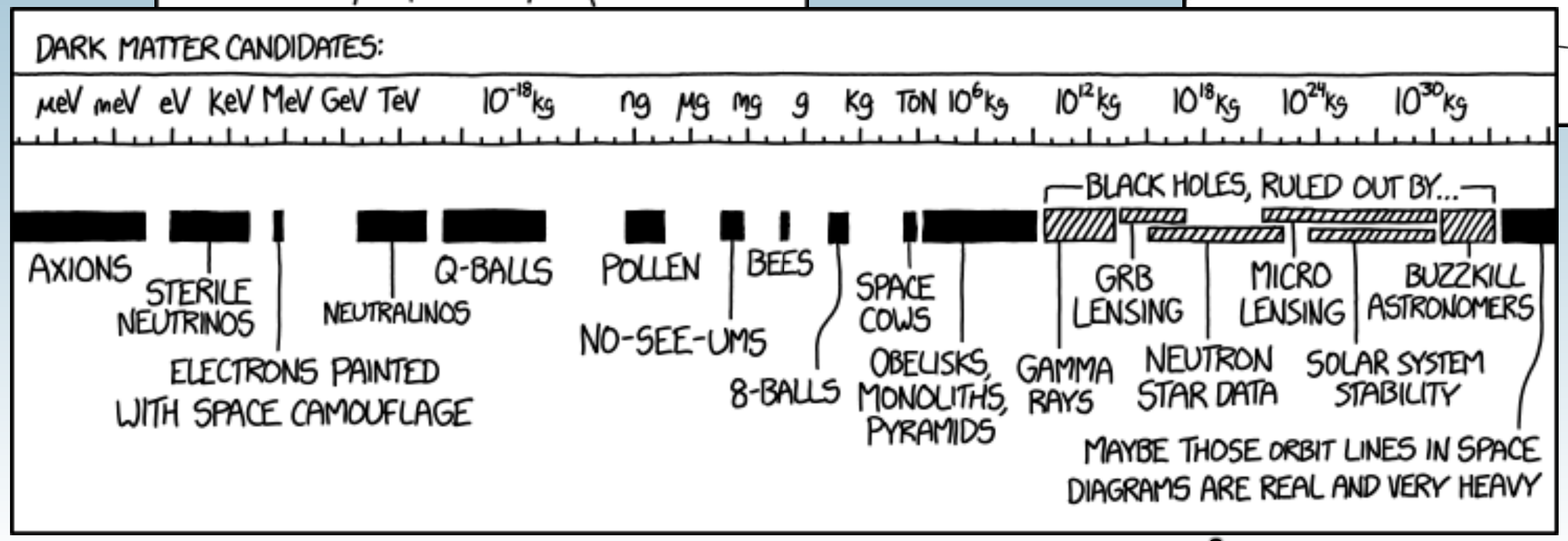
- Introduction
- LDM Candidates
- Signals at accelerators
- Current limits

See S. Trojanowski's talk tomorrow!

Introduction

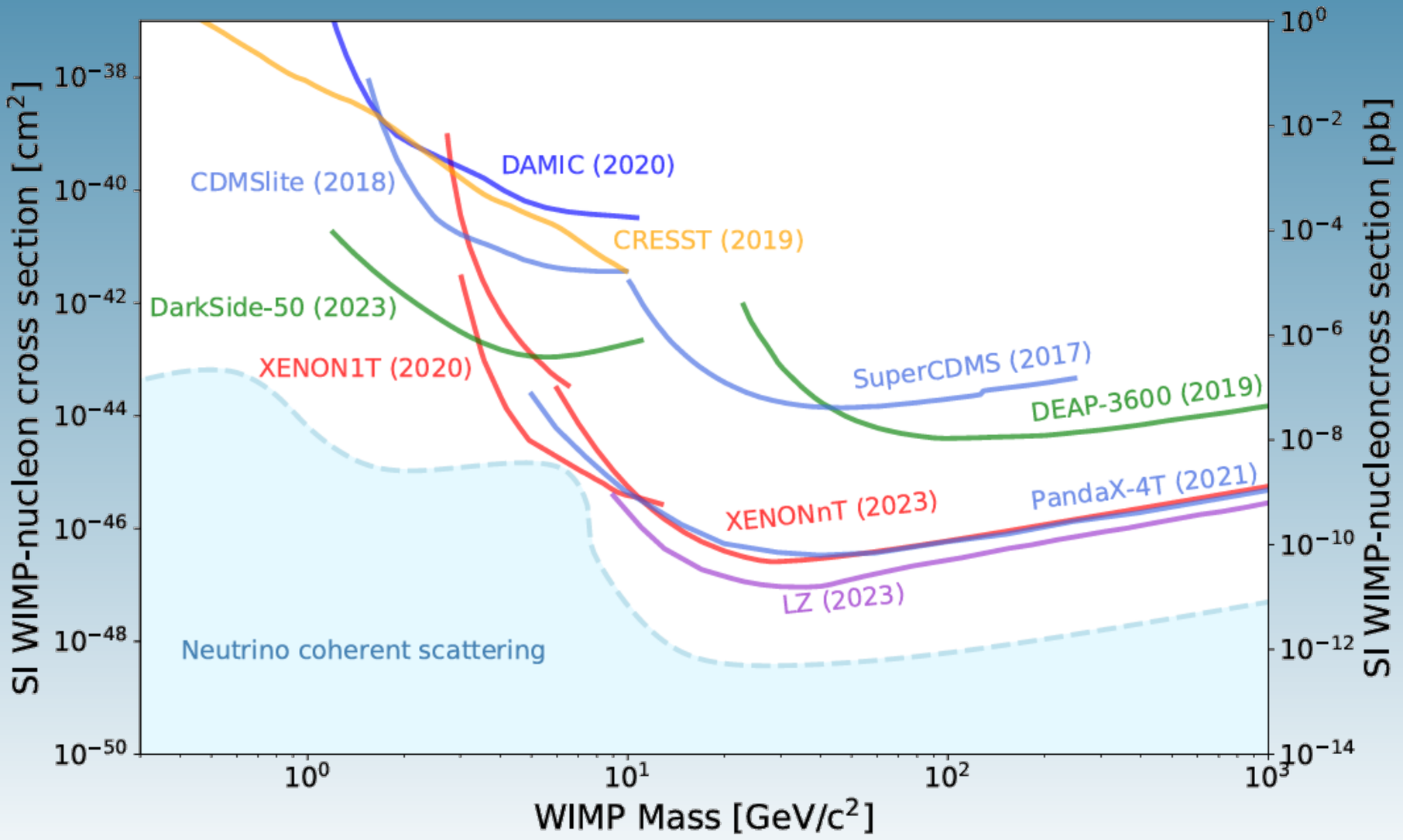






Credits: xkcd.com

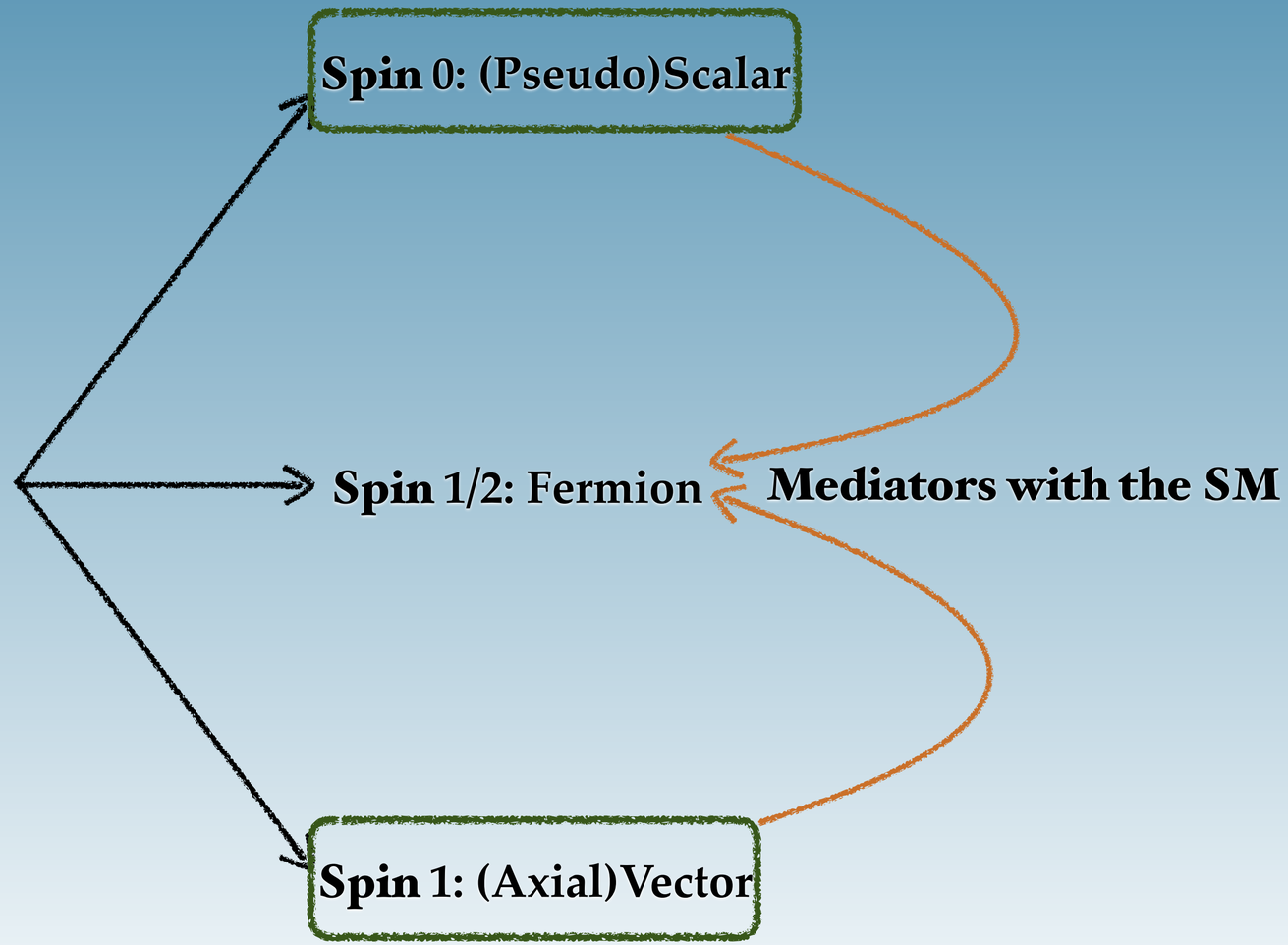
Introduction



Navas et al., PRD 110, 3, 030001. PDG 2024

Introduction

- Dark matter particle

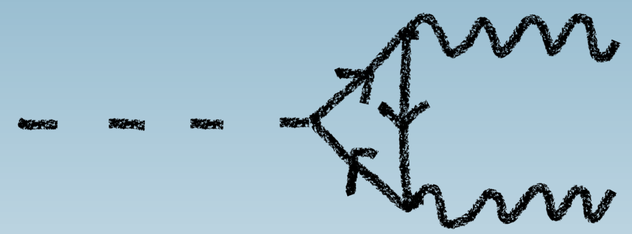


LDM Candidates - The Axion

- SM Lagrangian allows a purely gauge term

$$\theta_{QCD} \frac{\alpha_s}{8\pi} G^{a\mu\nu} \tilde{G}^{a}_{\mu\nu}$$

- Related to complex phases in quark mass matrix via the chiral anomaly



$$\bar{\theta} = \theta_{QCD} + \mathrm{Arg}(\mathrm{Det}(M_u M_d))$$

- The observable parameter, $\bar{\theta}$ is bound by neutron EDM, d_n

$$d_n \sim \bar{\theta} \cdot 10^{-16}\, e\text{-cm}, \quad \bar{\theta} \lesssim O(10^{-10})$$

Crewther, Di Vecchia, Veneziano & Witten, 1980

Baker et al., 0602020 Afach et al., 1509.04411

LDM Candidates - The Axion

- $\bar{\theta}$ becomes dynamical thanks to $U(1)_{PQ}$

Peccei and Quinn, PRL 38 (1977) 1440-1443 and PRD 16 (1977) 1791 1797

$$\mathcal{L}_{aGG} = \frac{a}{f_a}\frac{\alpha_s}{8\pi} G^{a\mu\nu}\tilde{G}^a_{\mu\nu} \longrightarrow \theta_{eff} = \bar{\theta} + \frac{a}{f_a}$$

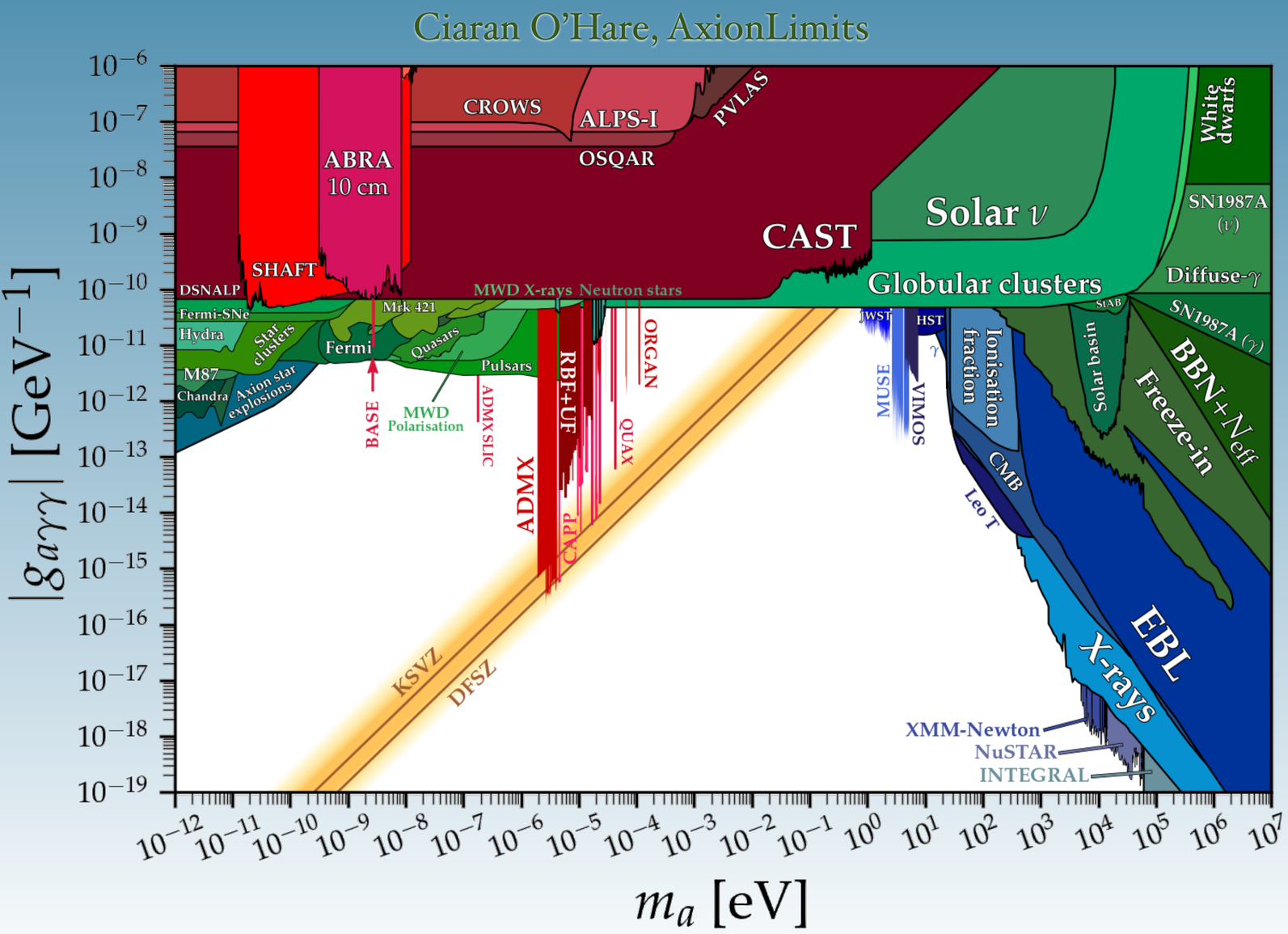
Weinberg, PRL 40 (1978) 223-226
Wilczek , PRL 40 (1978) 279-282

- Non-perturbative QCD potential ensures CP conservation

$$V_{eff} \sim 1 - \sqrt{1 + \cos\left(\bar{\theta} + \frac{a}{f_a}\right)} \longrightarrow \langle a \rangle = -f_a\bar{\theta} \; ; \; m_a \simeq 5.7\,\frac{10^9\,GeV}{f_a}\,meV$$

- Misalignment mechanism produces CDM axions
- Axion-like particles: $m_a \neq F(f_a)$

LDM Candidates - The Axion



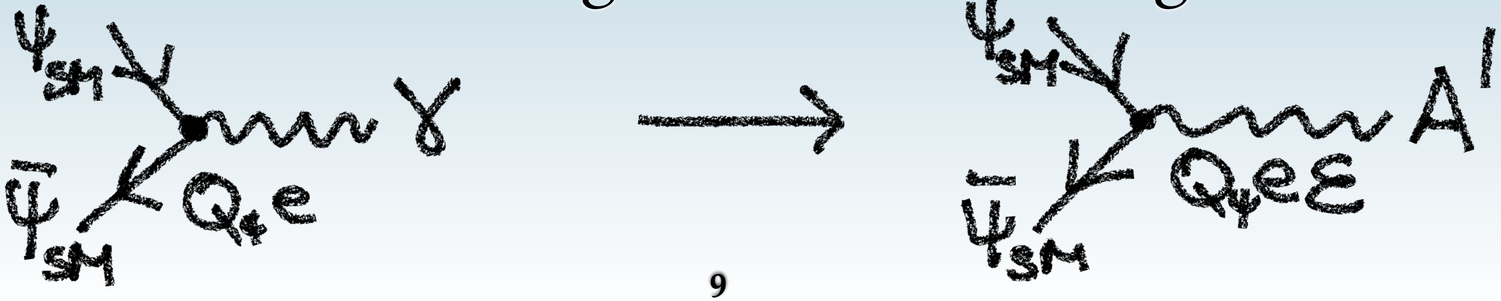
LDM Candidates - The Dark Photon

- There may be a fully secluded dark sector
- If a $U(1)_{DP}$ symmetry is present:

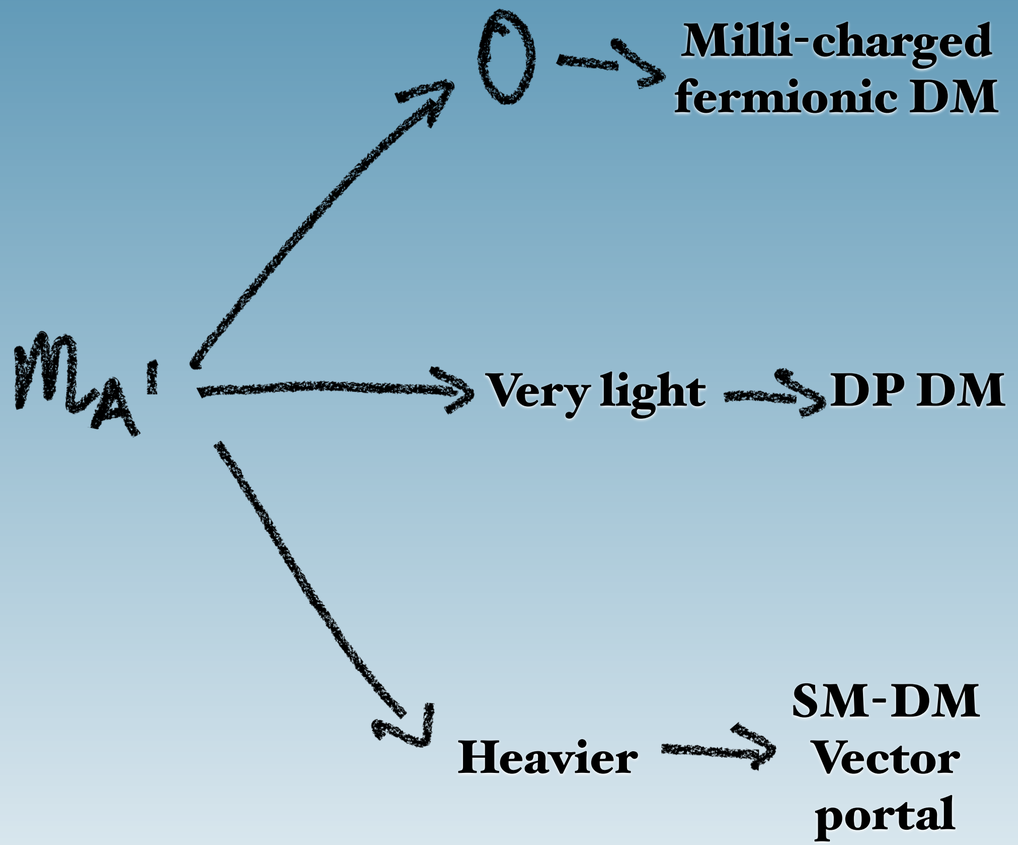
Fayet, NPB 187 (1981) 184
Okun, Sov. Phys. JETP 56 (1982) 502
Georgi, Ginsparg, Glashow, Nature 306 (1983) 765
Holdom, PLB 166 (1986) 196

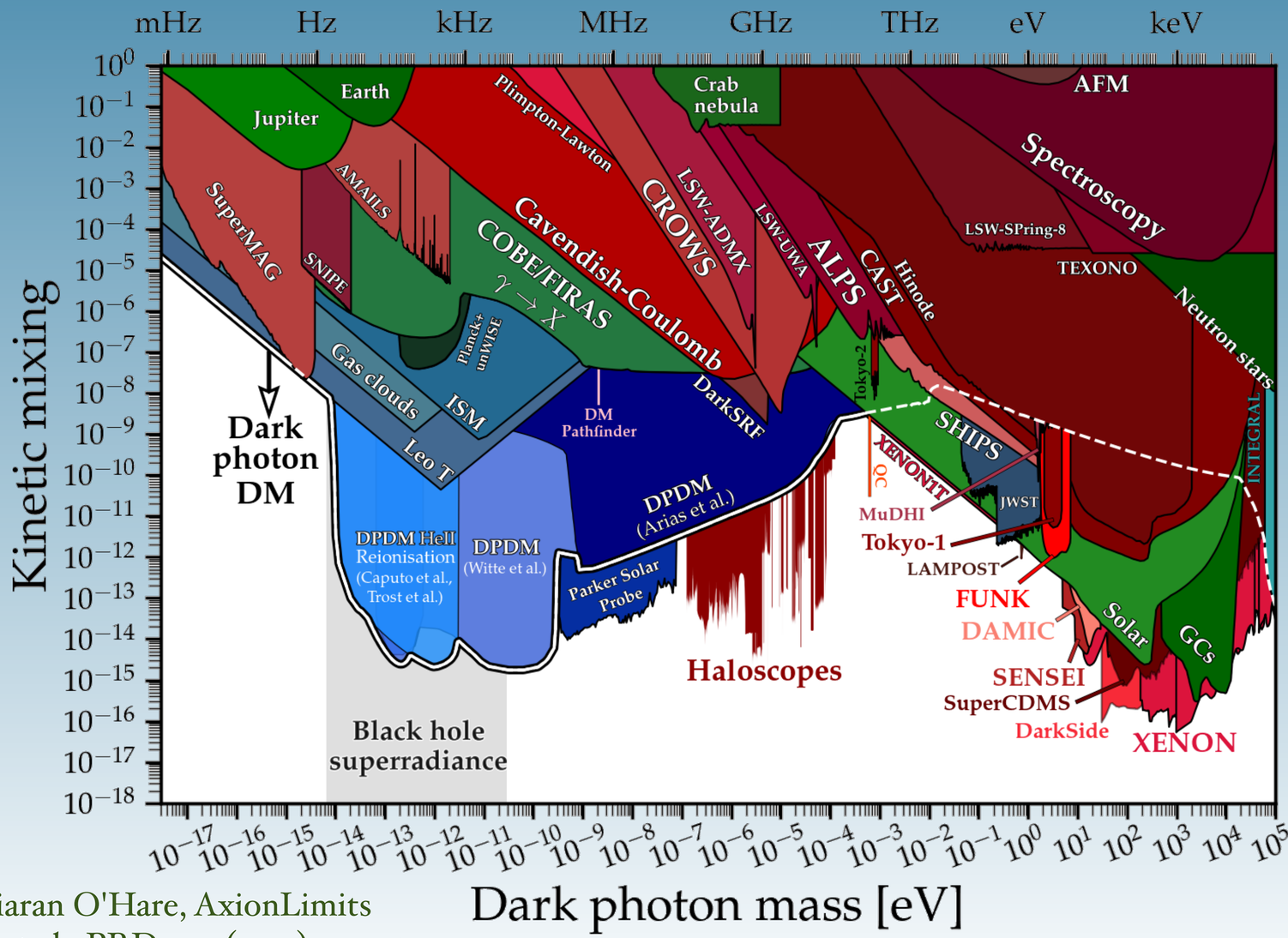
$$-\underbrace{\frac{1}{4}F_{\mu\nu}F^{\mu\nu}}_{U(1)_{EM}} - \underbrace{\frac{1}{4}F'_{\mu\nu}F^{\mu\nu}}_{U(1)_{DP}} - \underbrace{\frac{\varepsilon}{4}F'_{\mu\nu}F^{\mu\nu}}_{\gamma\text{-}A'}$$

- SM talks to dark sector through the kinetic mixing



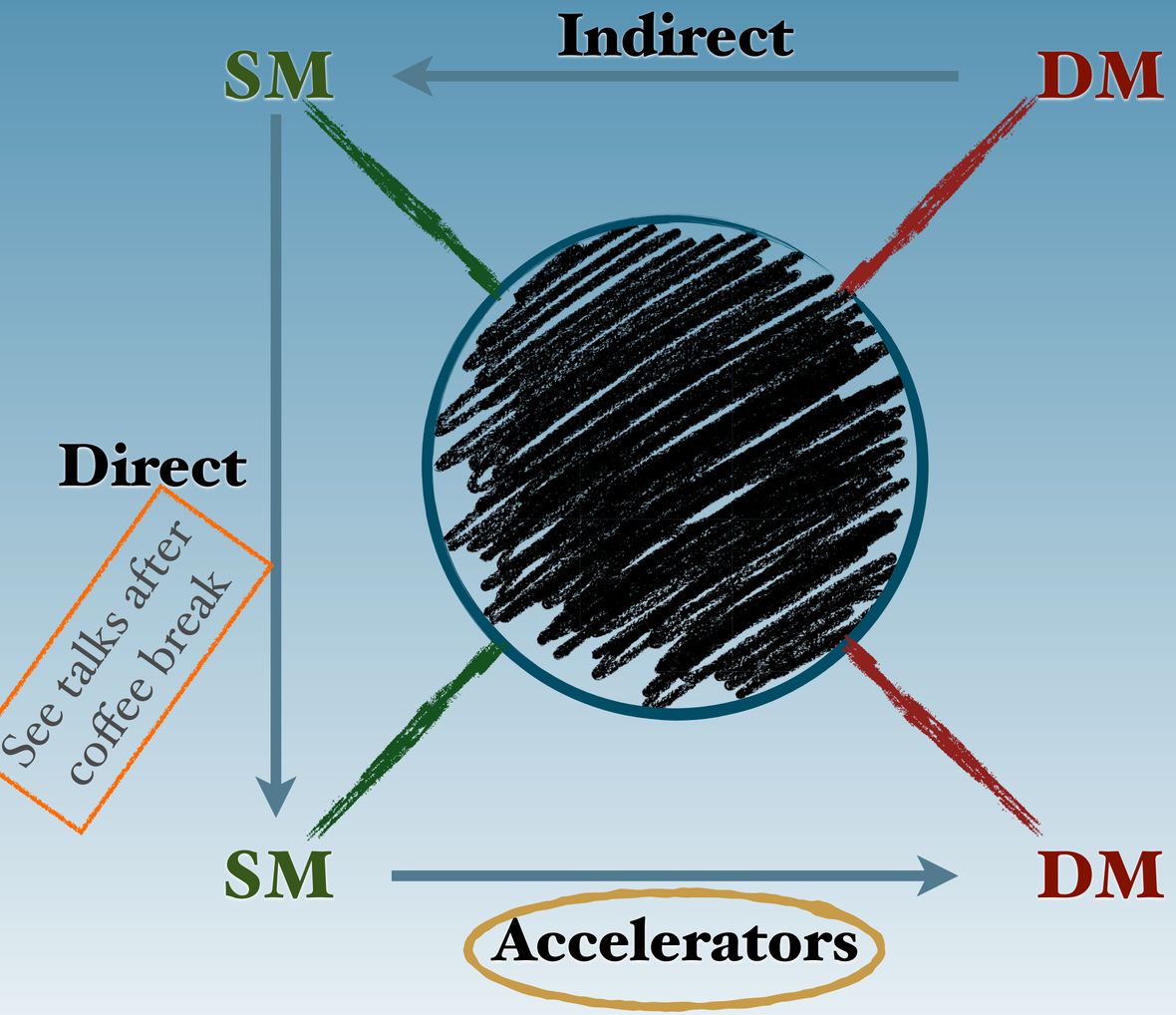
LDM Candidates - The Dark Photon

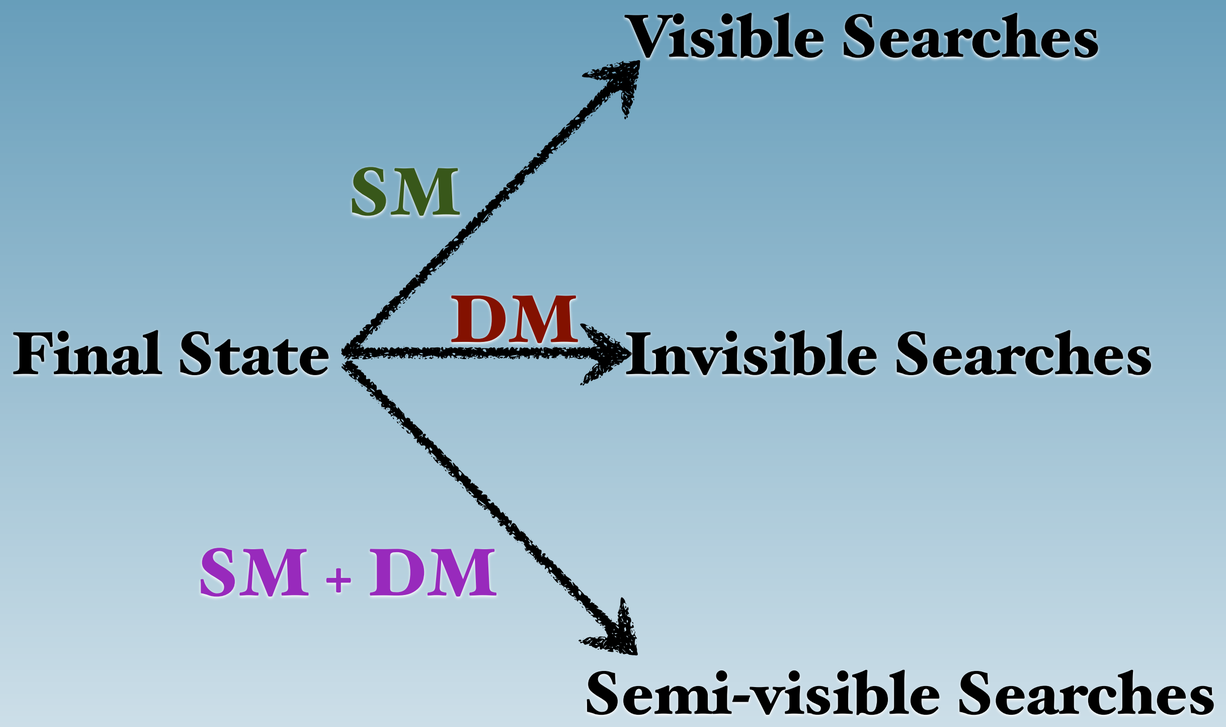




Ciaran O'Hare, AxionLimits
Caputo et al., PRD 104 (2021) 9, 095029

Signals at Accelerators

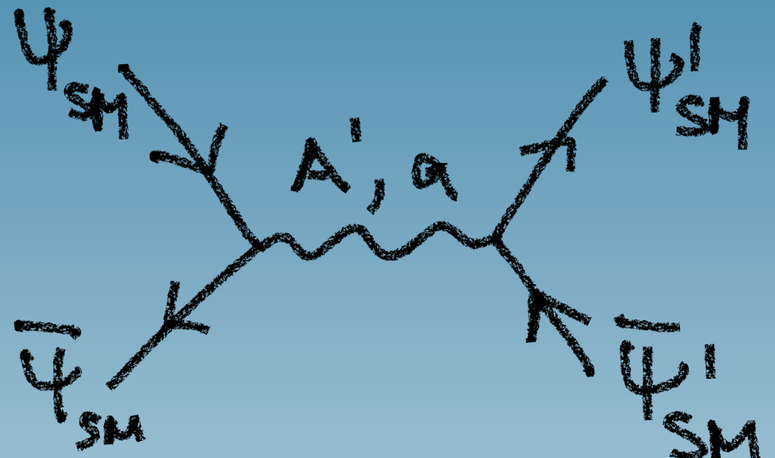




Signals at Accelerators - Visible Searches

- Dark sector particles fully decay within the detector
- Clear signals: bump hunts
- Full mass reconstruction is possible
- Cannot probe processes involving directly the DM candidate
- Prompt vs displaced vertices

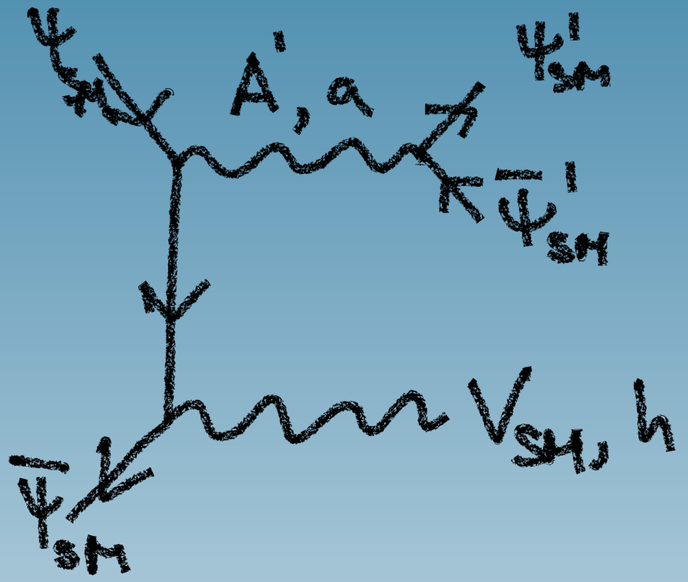
Signals at Accelerators - Visible Searches



Resonant production

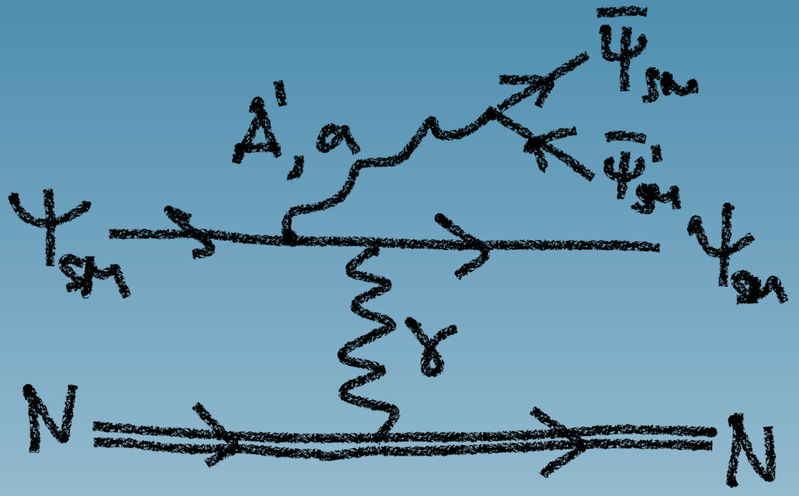
- Large production around resonant mass
- Bump hunt
- Sensitive to atomic electron motion

See G. Grilli di Cortona's talk tomorrow!



Associated production

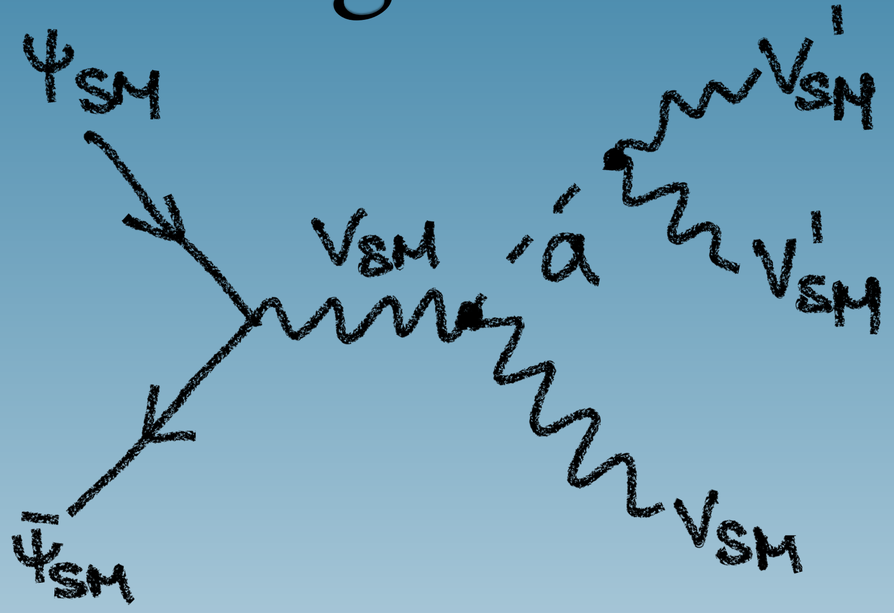
- Broad production
- SM boson tagging
- α and phase space suppression



Bremsstrahlung

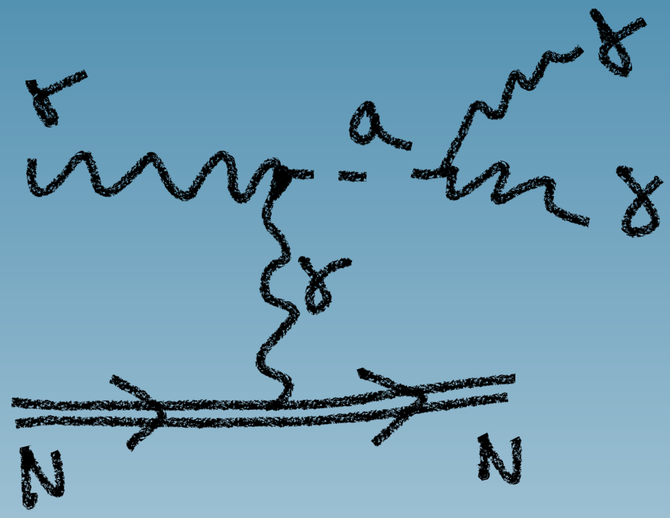
- Broad spectrum
- α^2 and phase space suppression
- Z^2 coherent enhancement
- Z non-coherent enhancement

Signals at Accelerators - Visible Searches



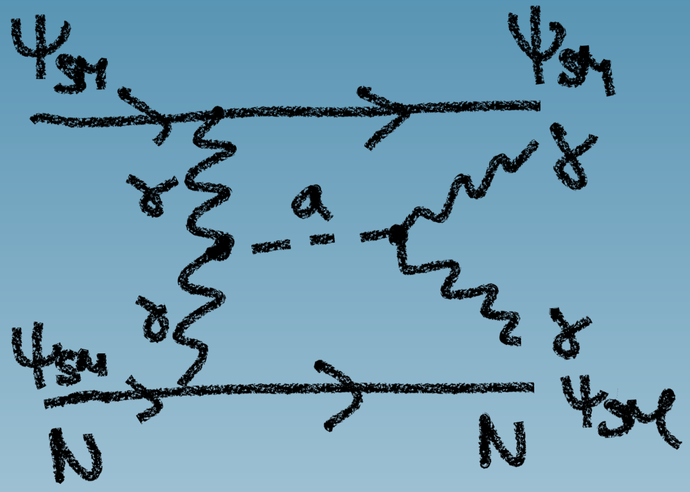
ALP-strahlung

- Main process in the absence of fermion couplings
- Varied topology depending on V stability



Primakoff

- Uses secondary photons in beam dumps
- Large in thick targets
- Z^2 coherent enhancement
- Z non-coherent enhancement



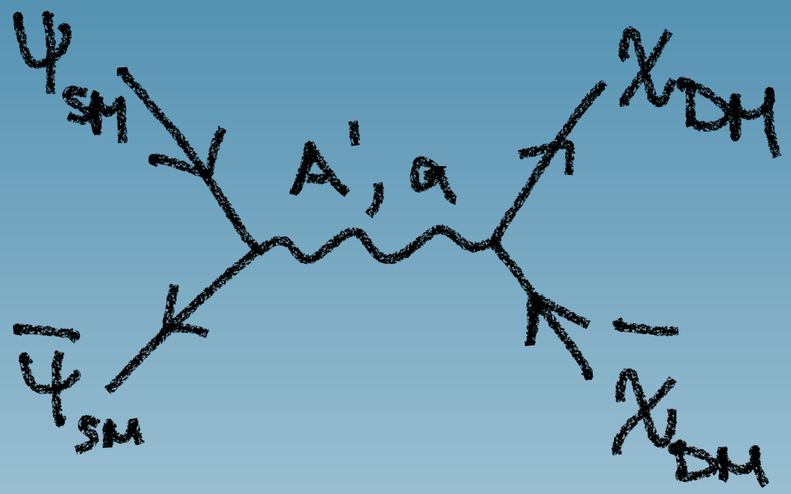
Photon fusion

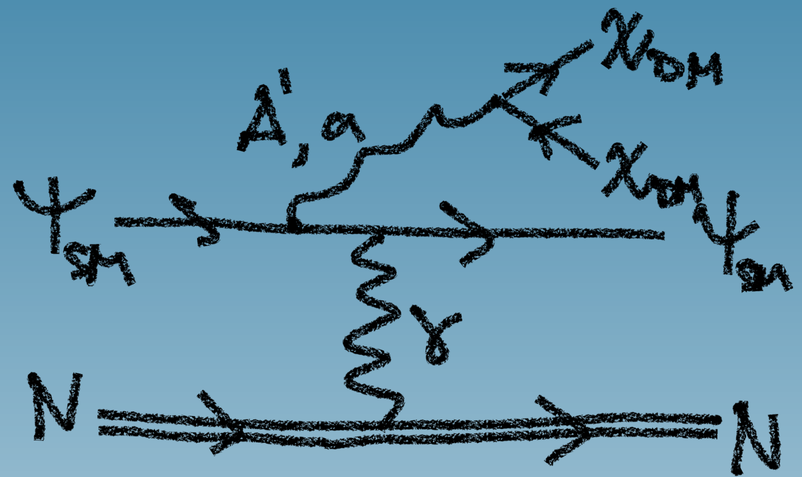
- Present in fixed-target and colliders
- α suppression
- Z^2 coherent enhancement
- Z non-coherent enhancement

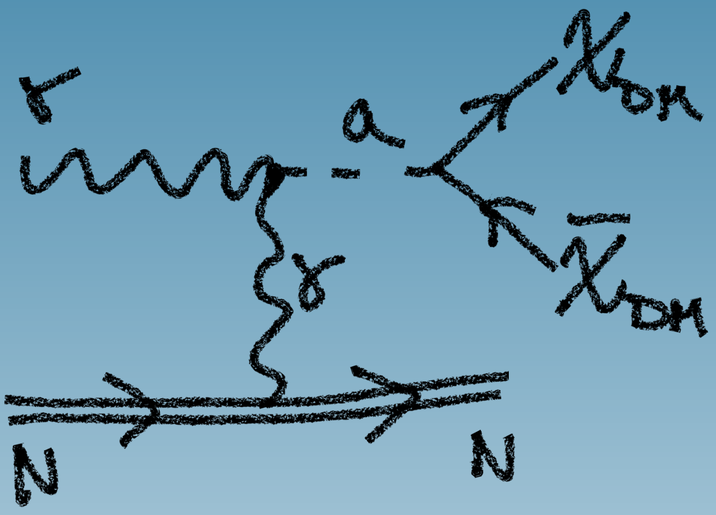
Signals at Accelerators - Invisible Searches

- No SM particles in final state
- Beam particle absorbed and measured in a target
- Missing energy or momentum if massive dark particle is emitted
- Produced particle can be stable or decay into light dark states
- Can set limits on fermionic DM

Signals at Accelerators - Invisible Searches







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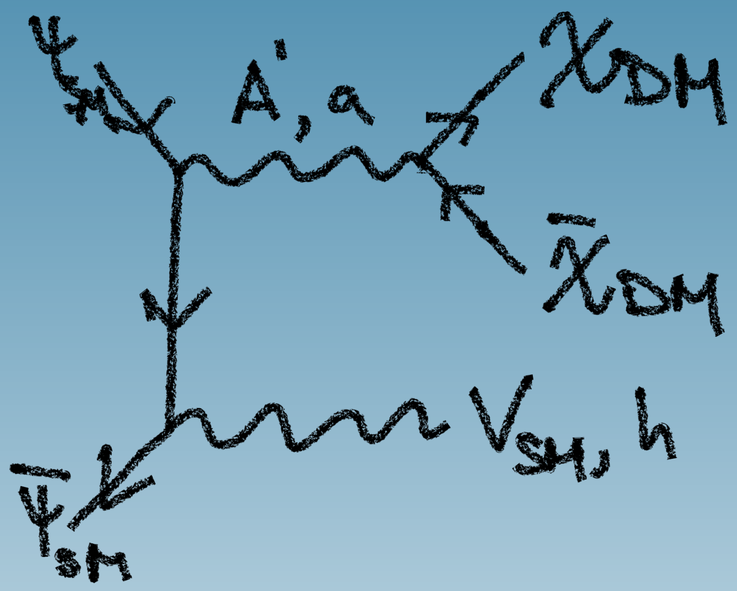
Primakoff

- Uses secondary photons in beam dumps
- Large in thick targets
- Z^2 coherent enhancement
- Z non-coherent enhancement

Signals at Accelerators - Semi-visible Searches

- Mixed final state: SM and dark sector
- Clear signals: mono-X
- Missing mass and momentum searched
- Produced particle can be stable or decay into light dark states
- Can set limits on fermionic DM

Signals at Accelerators - Semi-visible Searches



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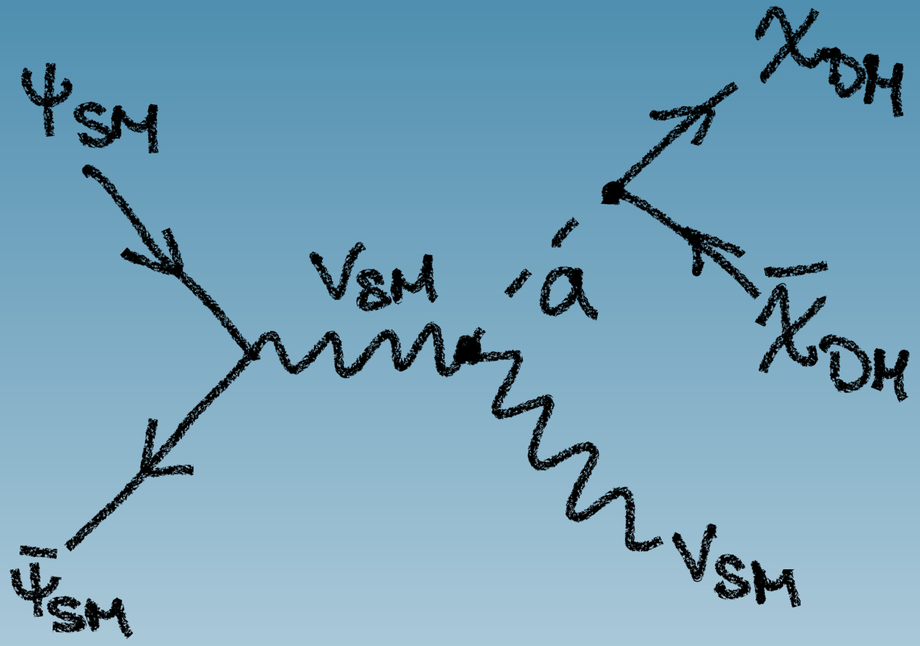

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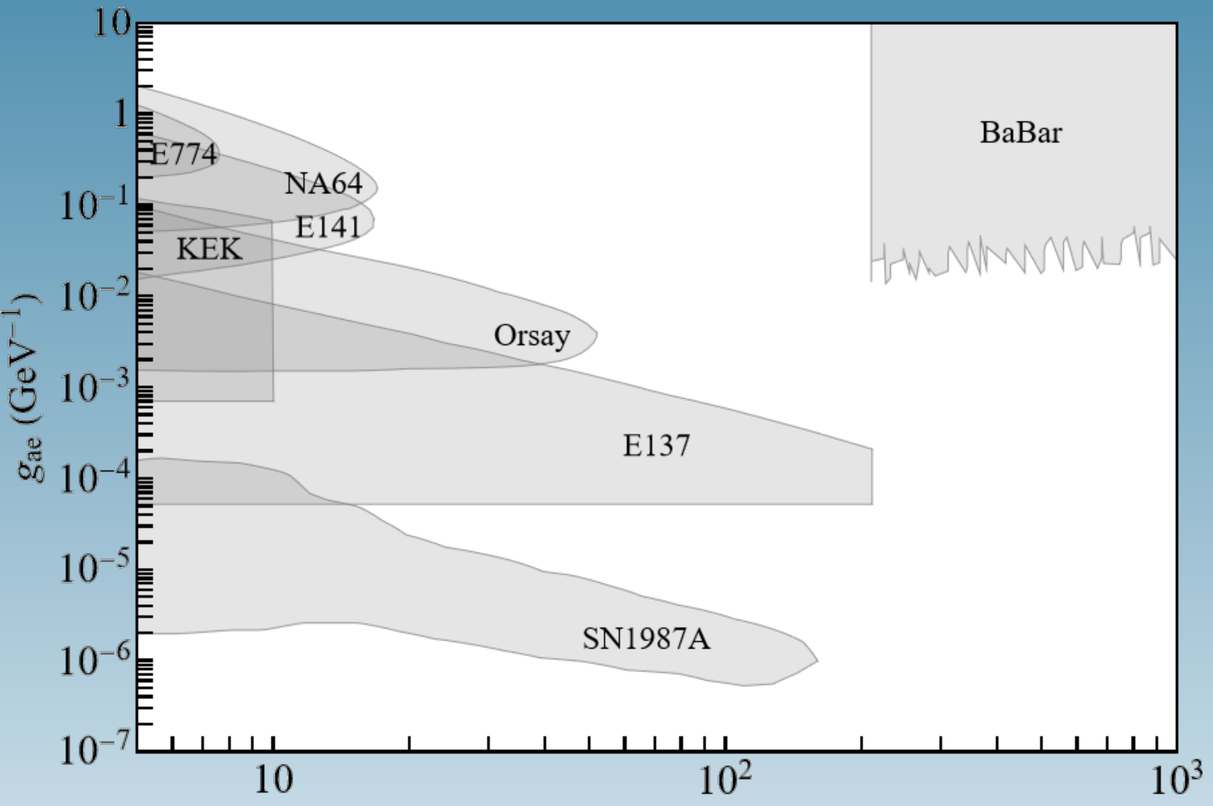
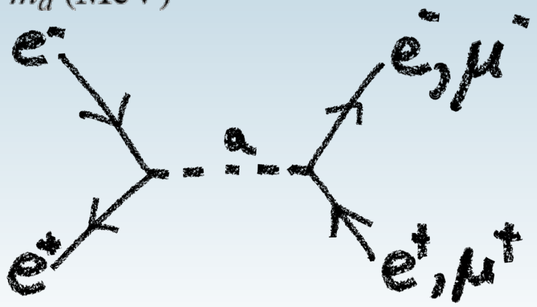
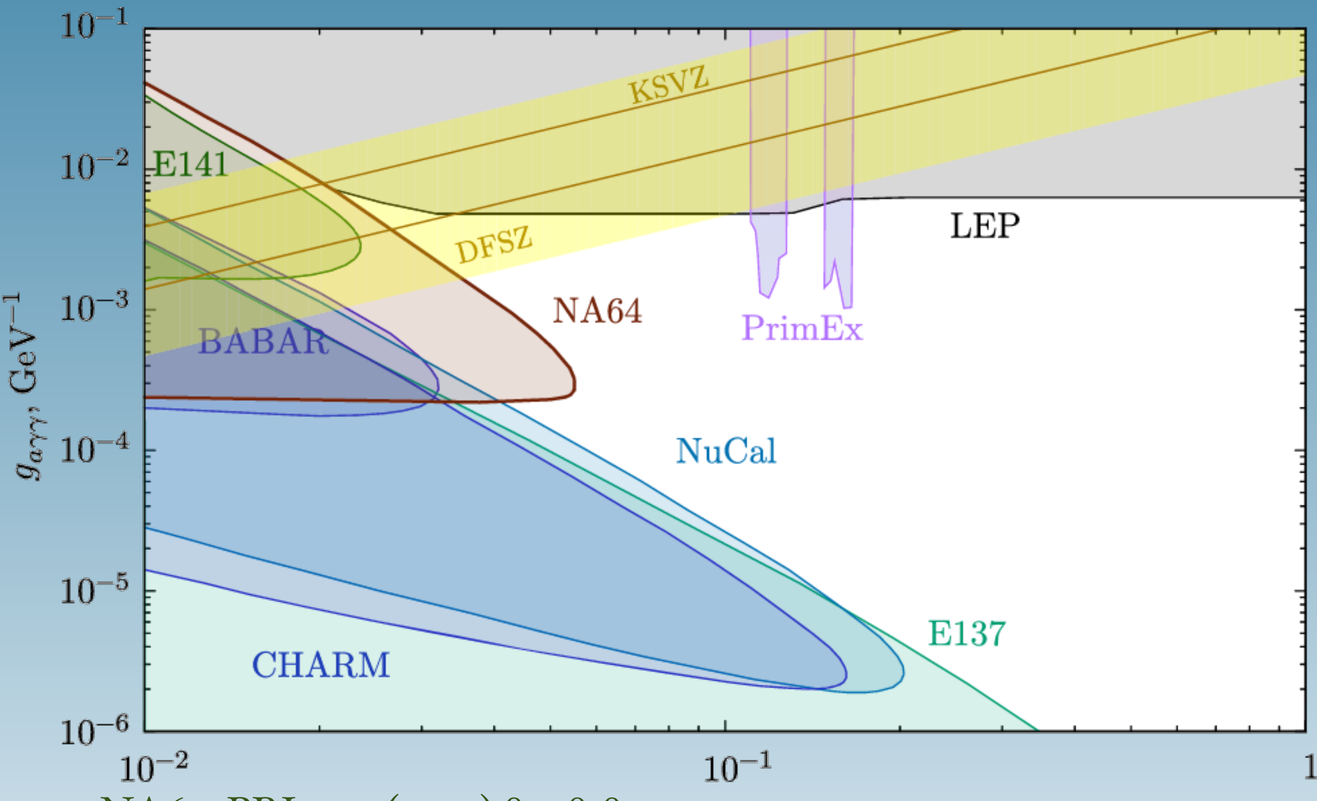
Current Limits - Pseudoscalars

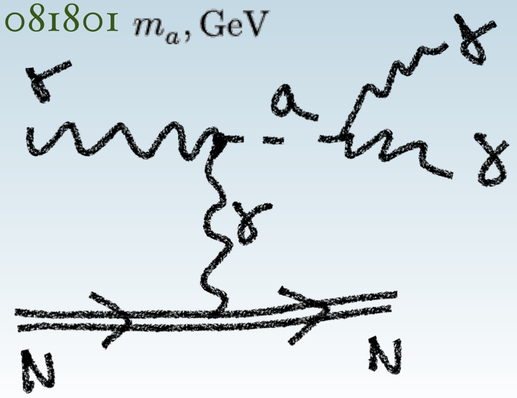


Adapted from FAA, Grilli di Cortona, Nardi, Veissière, 2504.00100





NA64, PRL, 125 (2020) 8, 081801



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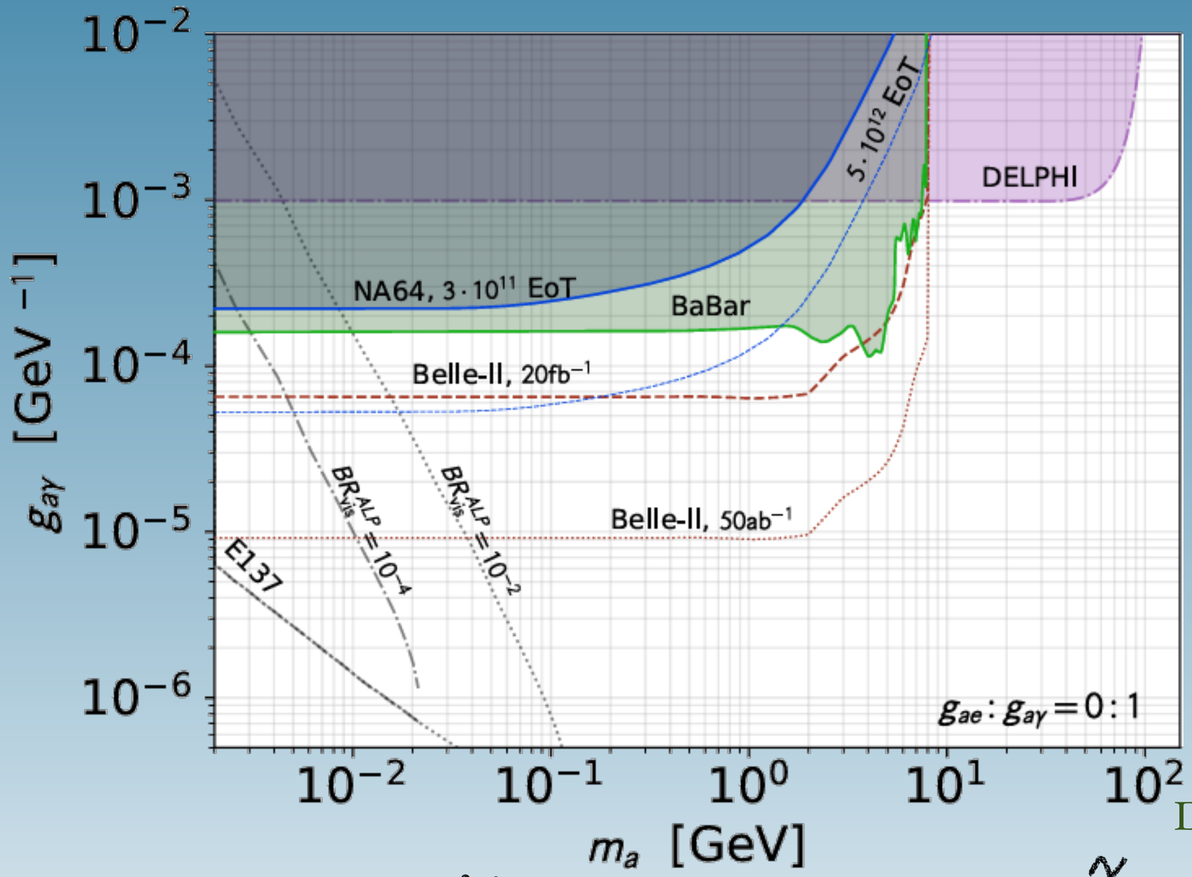
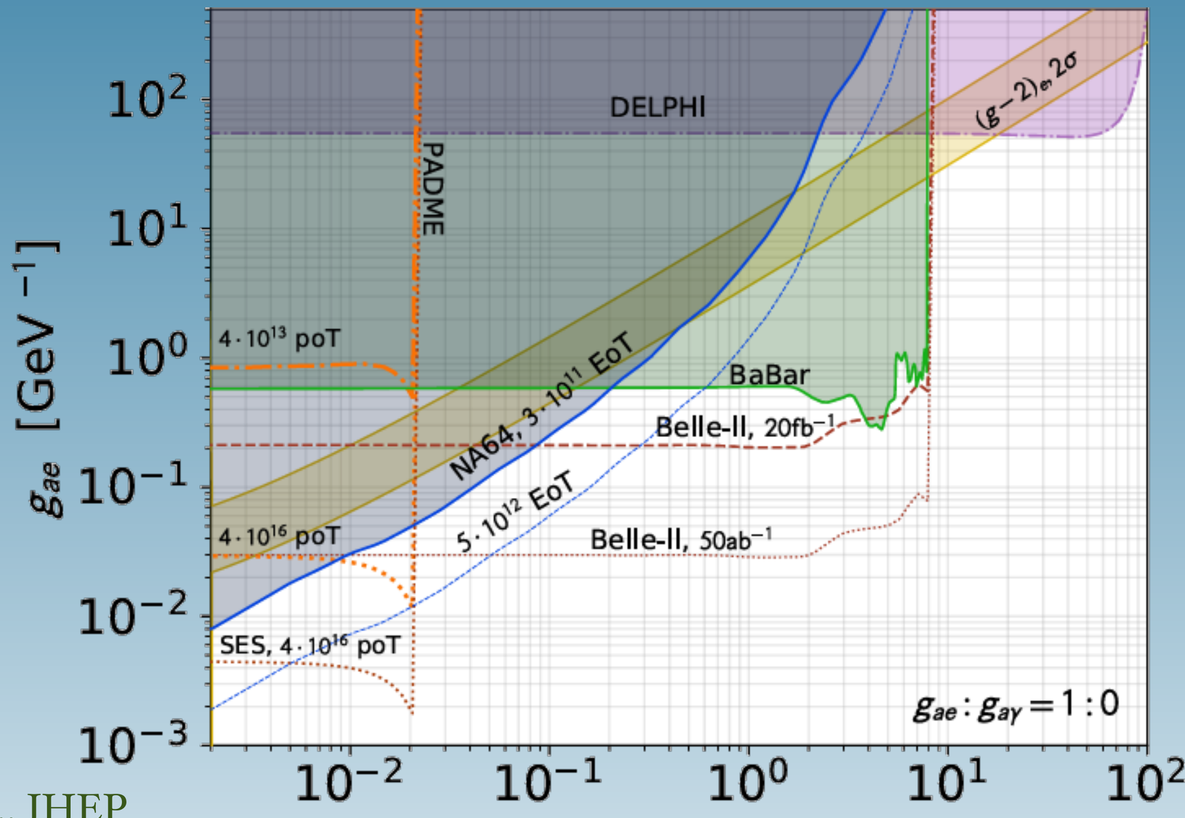
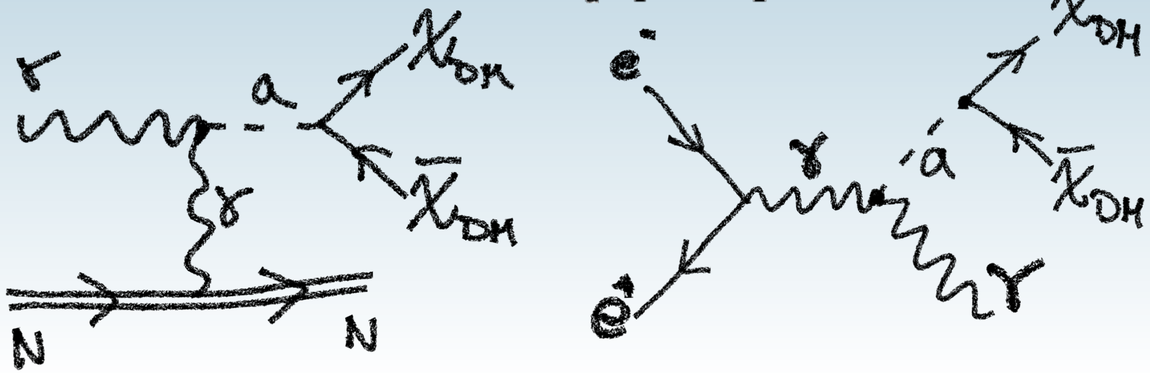
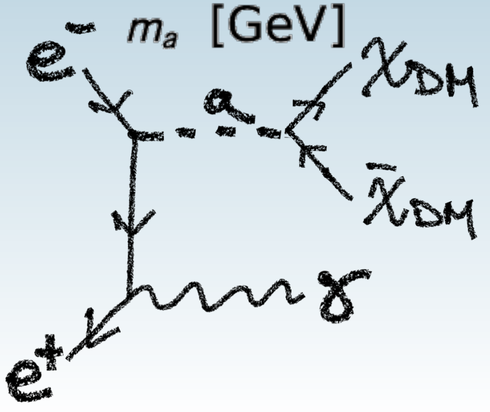


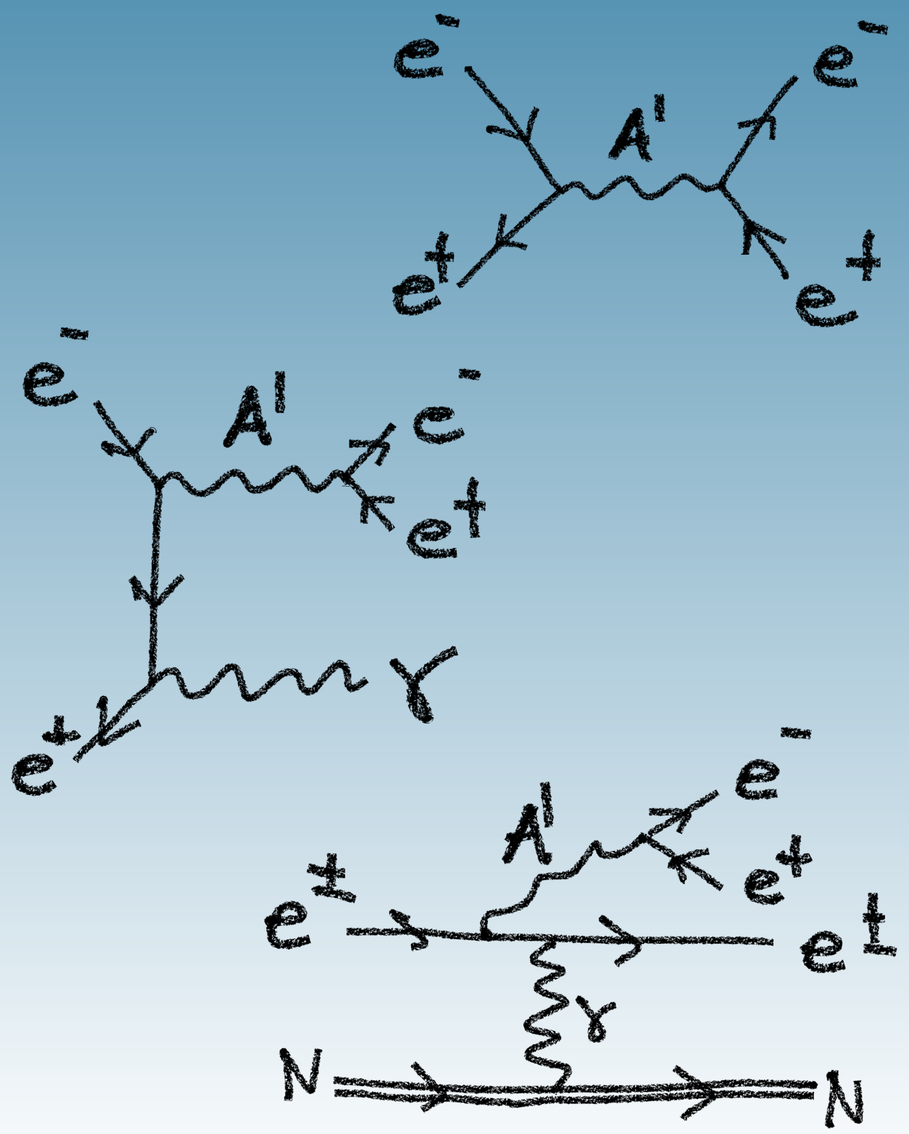


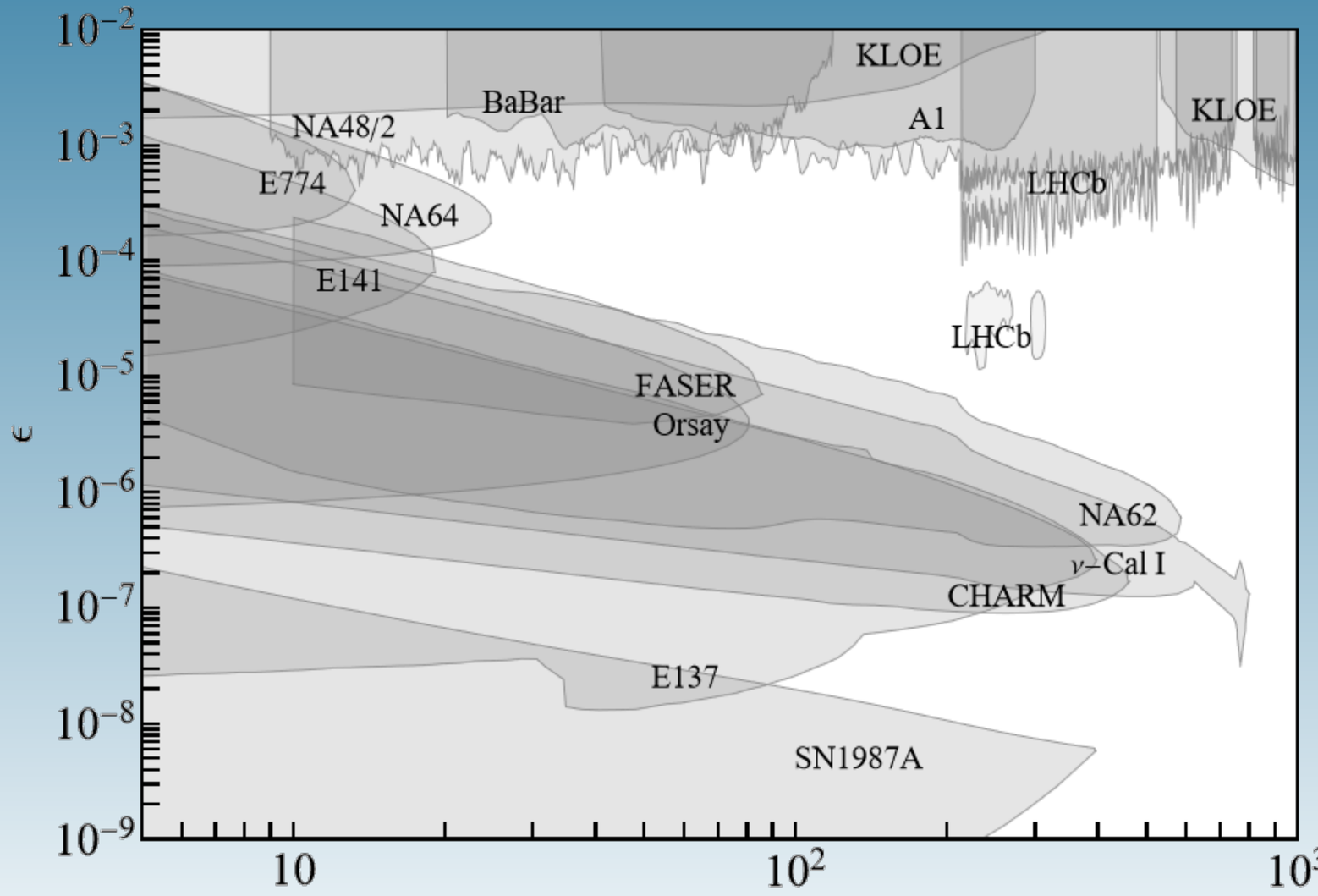
Darmé et al., JHEP 06 (2021) 009





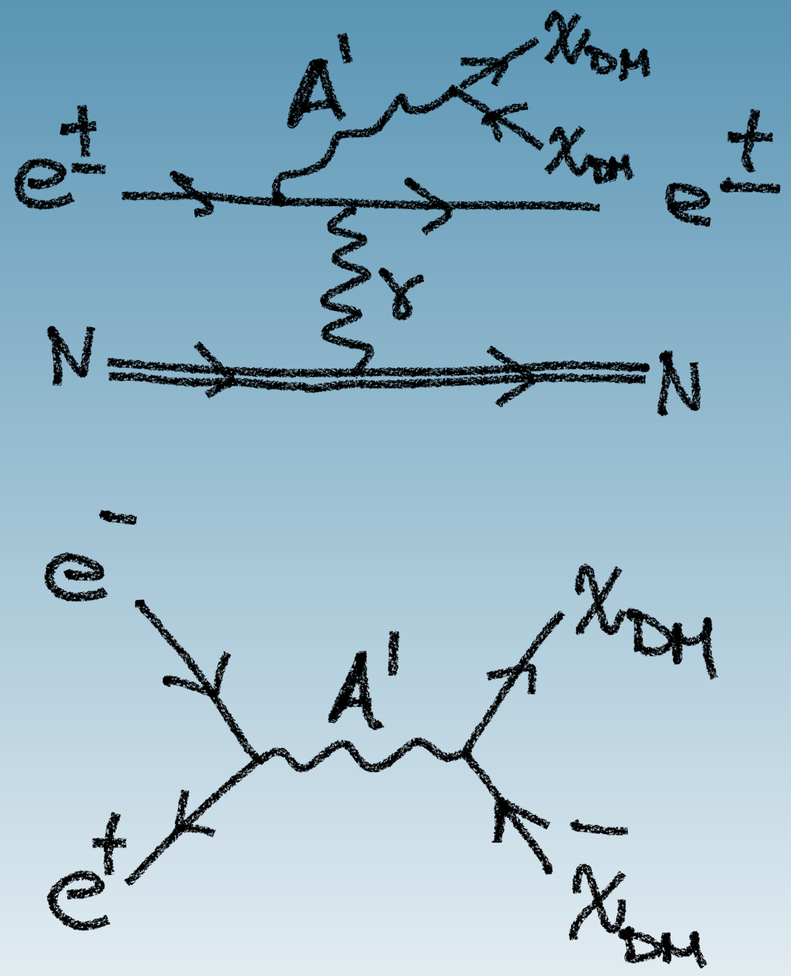
Current Limits - Vectors

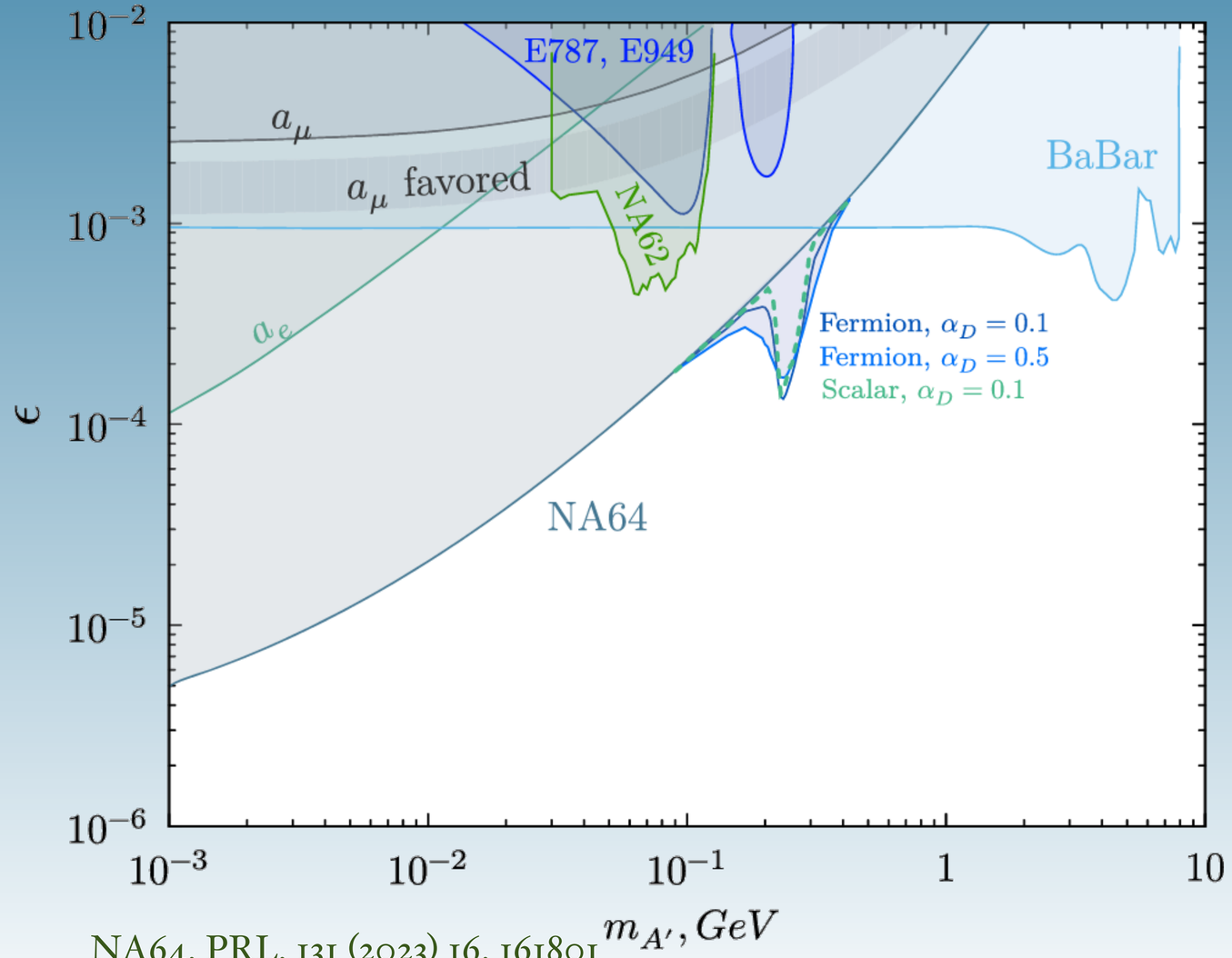




Adapted from FAA, Grilli di Cortona, Nardi, Veissière, 2504.00100

Current Limits - Vectors





NA64, PRL, 131 (2023) 16, 161801

Conclusions

- Unsuccessful WIMP searches so far call for other solutions
- LDM is motivated also by other open problems
- Accelerators provide strong bounds on mediators
- Large theoretical and experimental efforts for improvement
- Astrophysics and cosmology complement accelerator searches

Thank you for your attention