Current Dark Matter theory and motivation for APEX

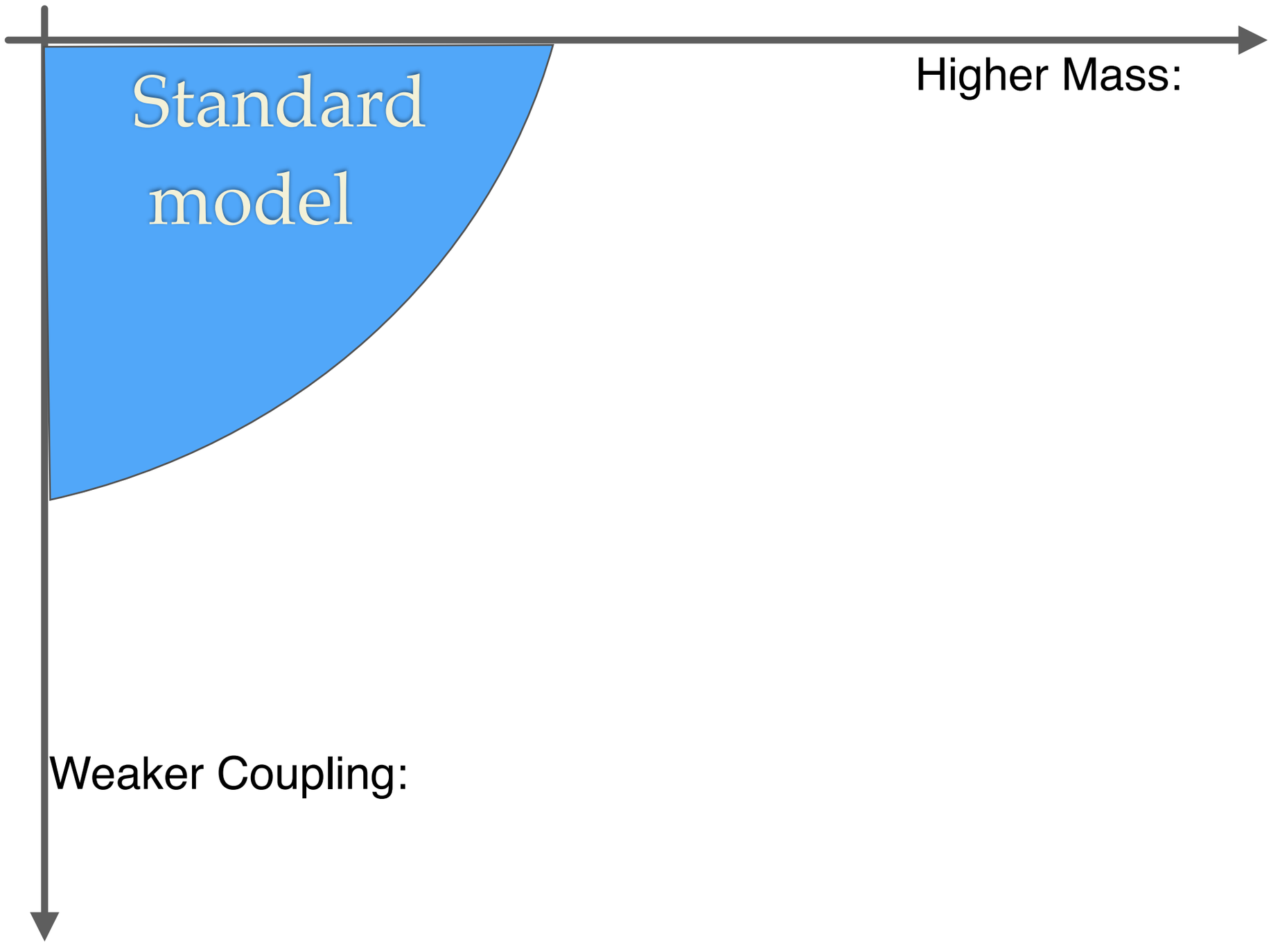
Natalia Toro (SLAC)

APEX Collaboration Meeting
July 24, 2018

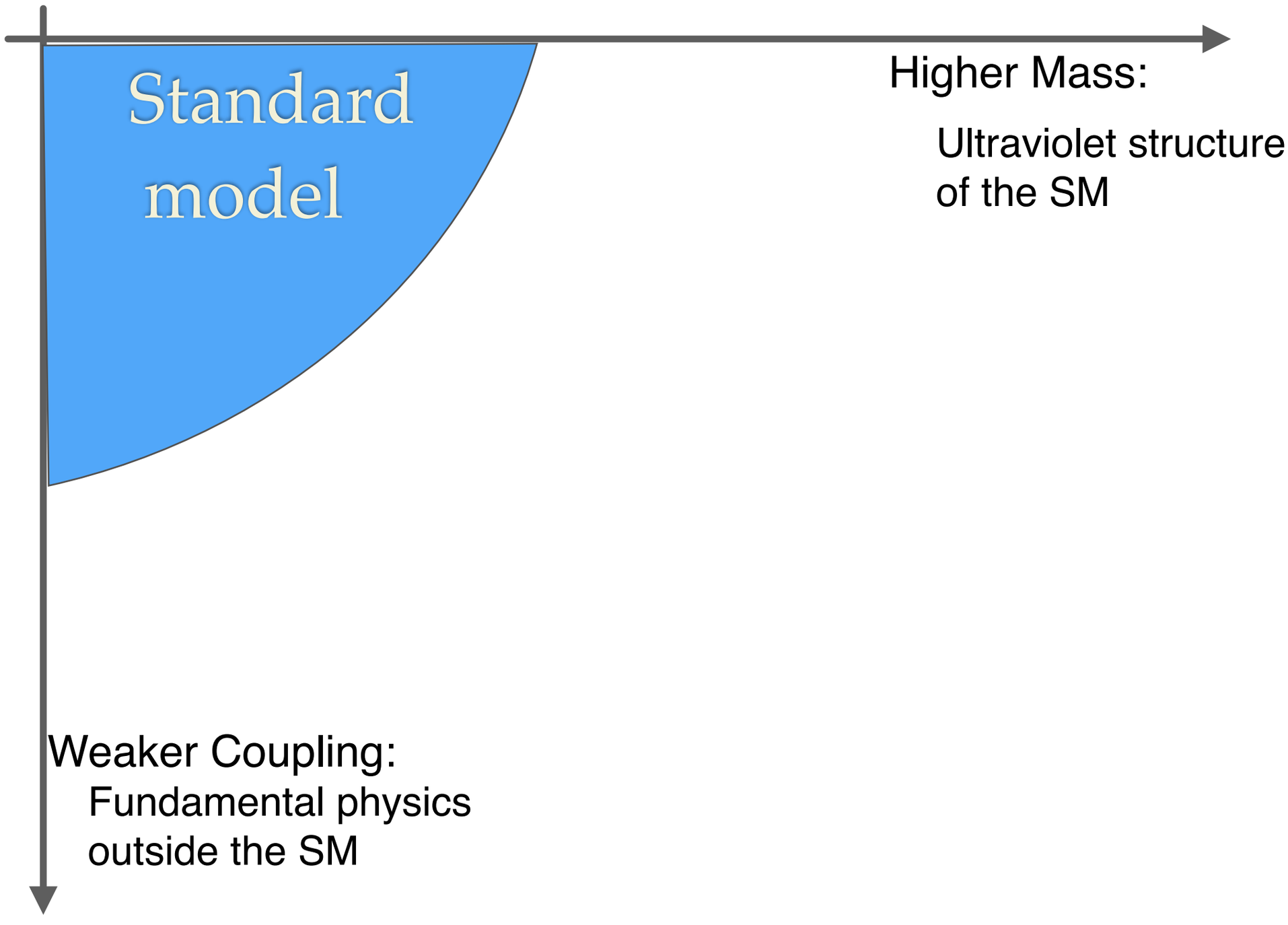
Introduction

- ✦ Broad theoretical context for APEX
- ✦ APEX and the world status of dark photon searches
- ✦ Motivations for the APEX parameter space

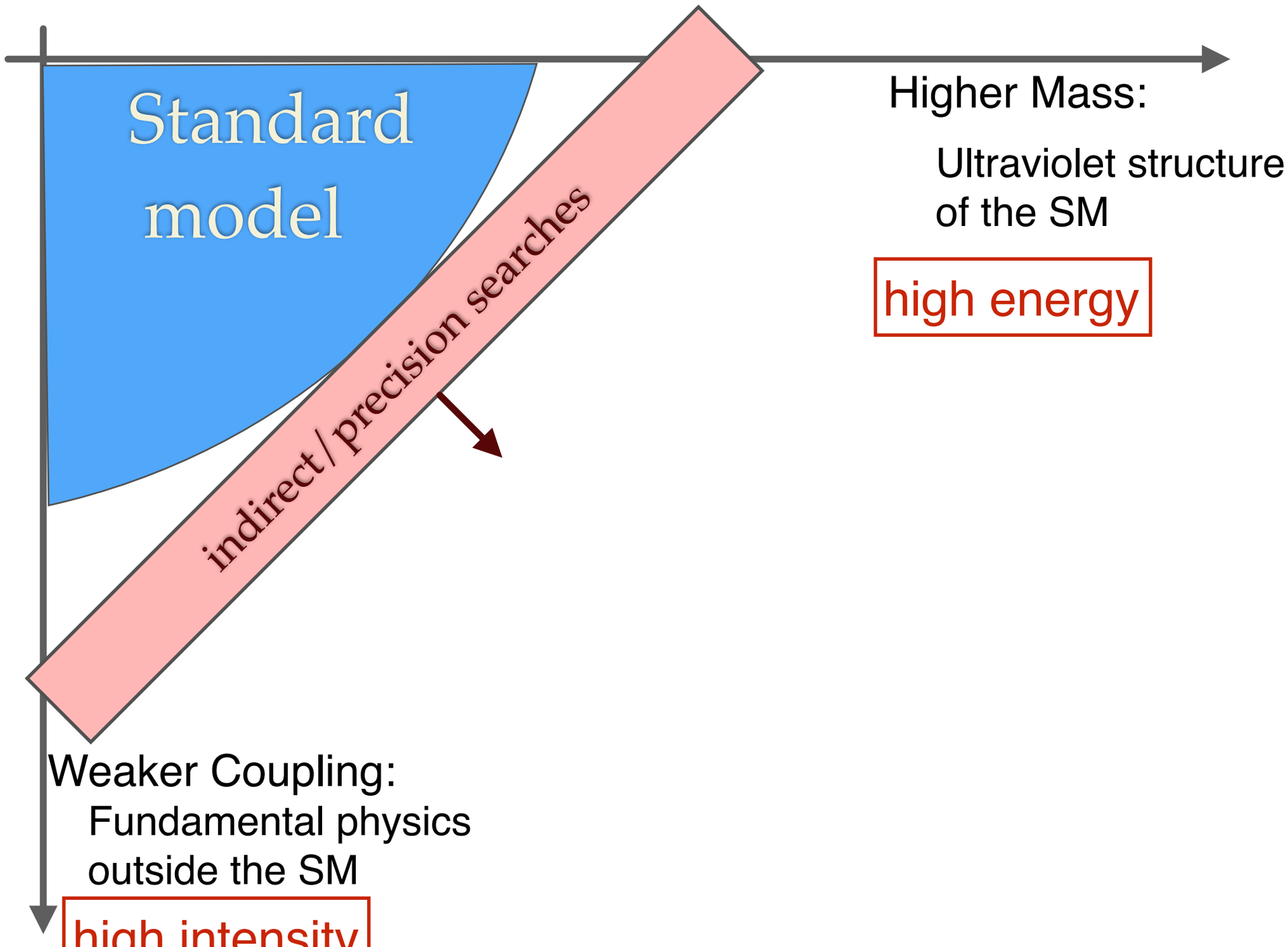
Searching For New Physics



Searching For New Physics



Searching For New Physics

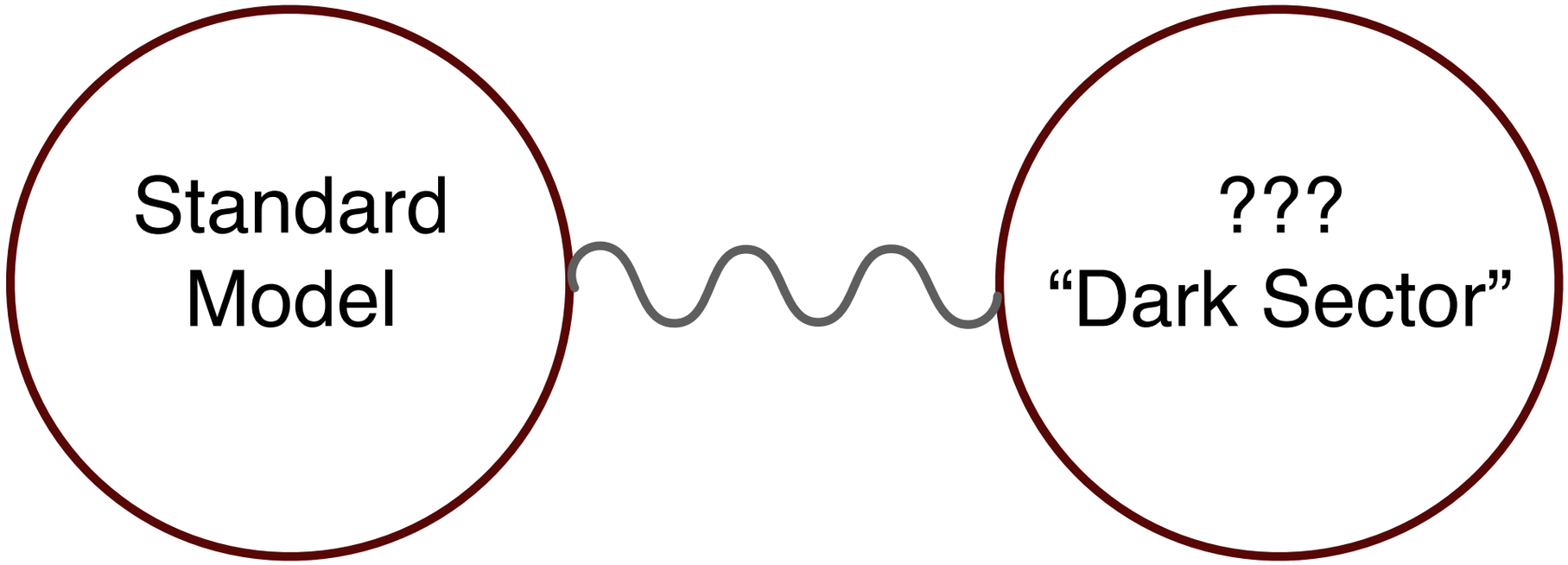


Looking Beyond the Standard Model

Most interactions between new physics and Standard Model are highly energy-suppressed, due to symmetries of SM!

The few allowed couplings are our pathways to discovery!

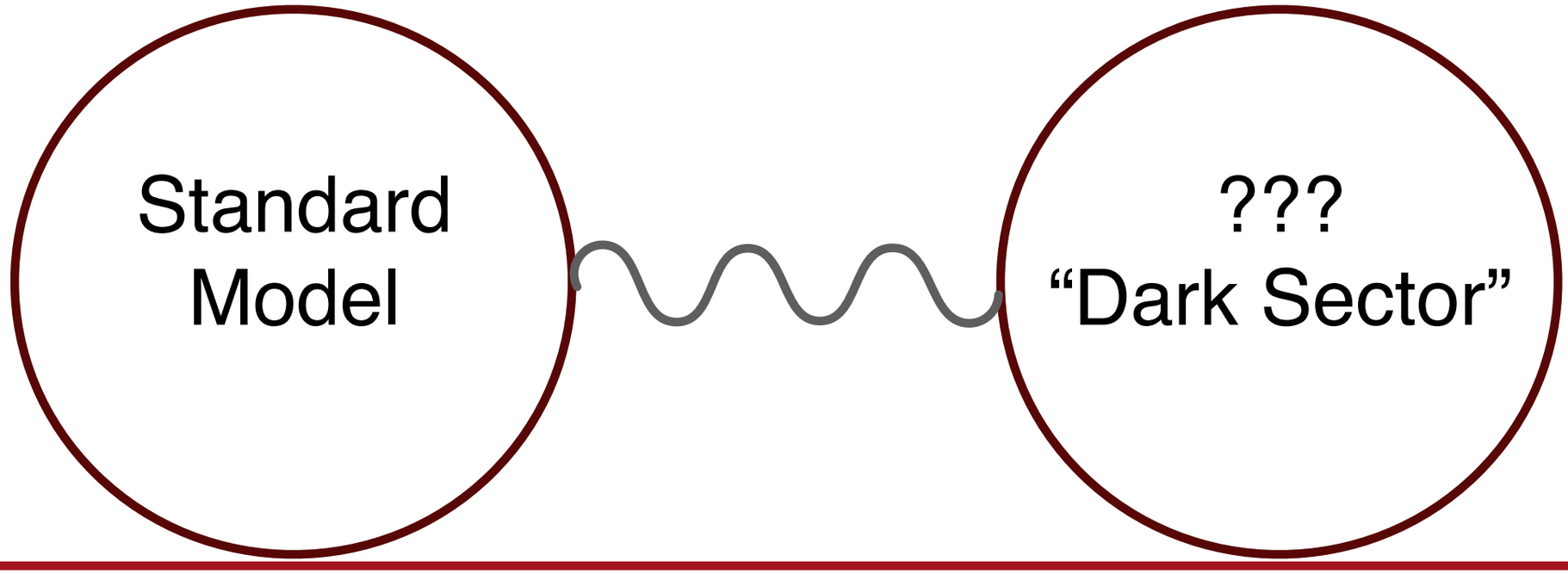
Looking Beyond the Standard Model



1) A new gauge boson A' can kinetically mix with SM photon:
   → small coupling to familiar matter proportional to its charge
2) A new scalar boson can mix with Higgs → small coupling prop. to quark & lepton masses *highly constrained by meson decays*
3) A new fermion can mix with neutrinos → rare higgs decays, production in neutrino scattering *very hard to detect*

SM extensions allow more general couplings

Looking Beyond the Standard Model



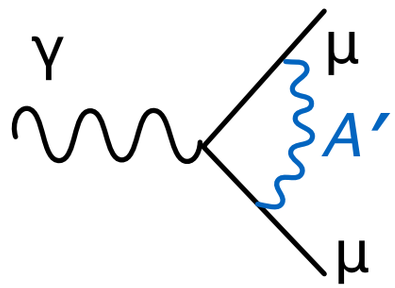
1) A new gauge boson A' can kinetically mix with SM photon:
   → small coupling to familiar matter proportional to its charge

"Dark photon" is both a well-motivated scenario and an approximate stand-in for many of the viable "generalized" interaction types
(e.g. B-L gauge boson, leptophilic scalar)

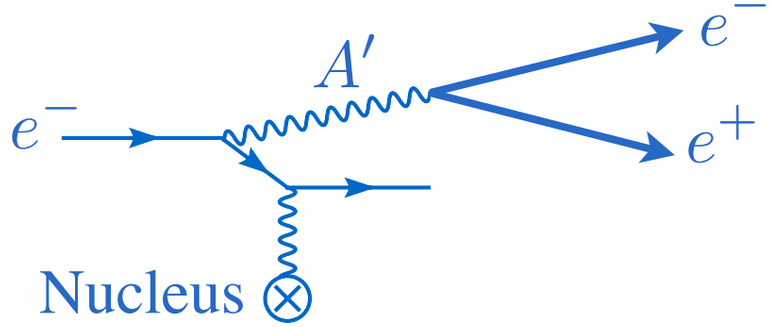
Searching for Dark Photons

Exploit coupling to electrons, protons, or muons!

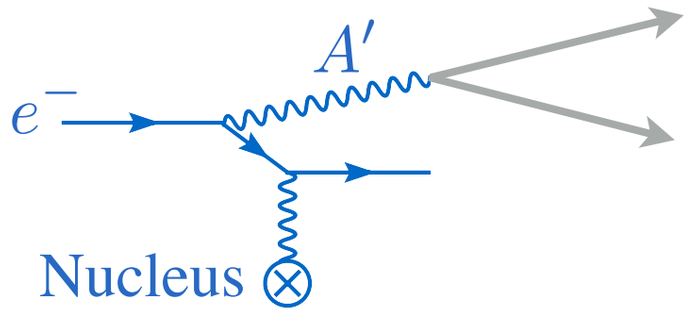
1. Corrections to precision physics (e.g. g-2) corrections



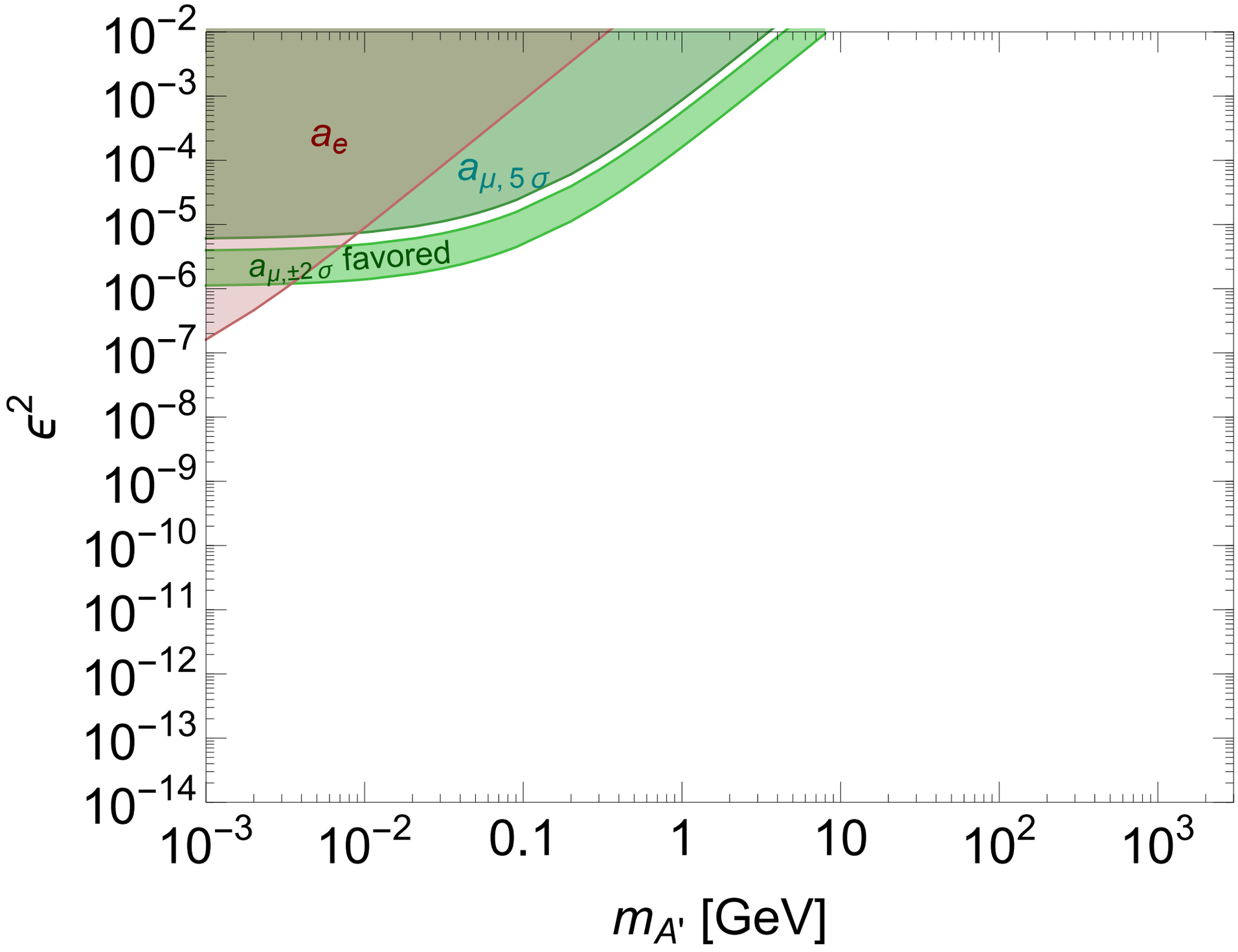
2. SM decays (via kinetic mixing)



3. Invisible decays (into the dark sector, if kinematically allowed)

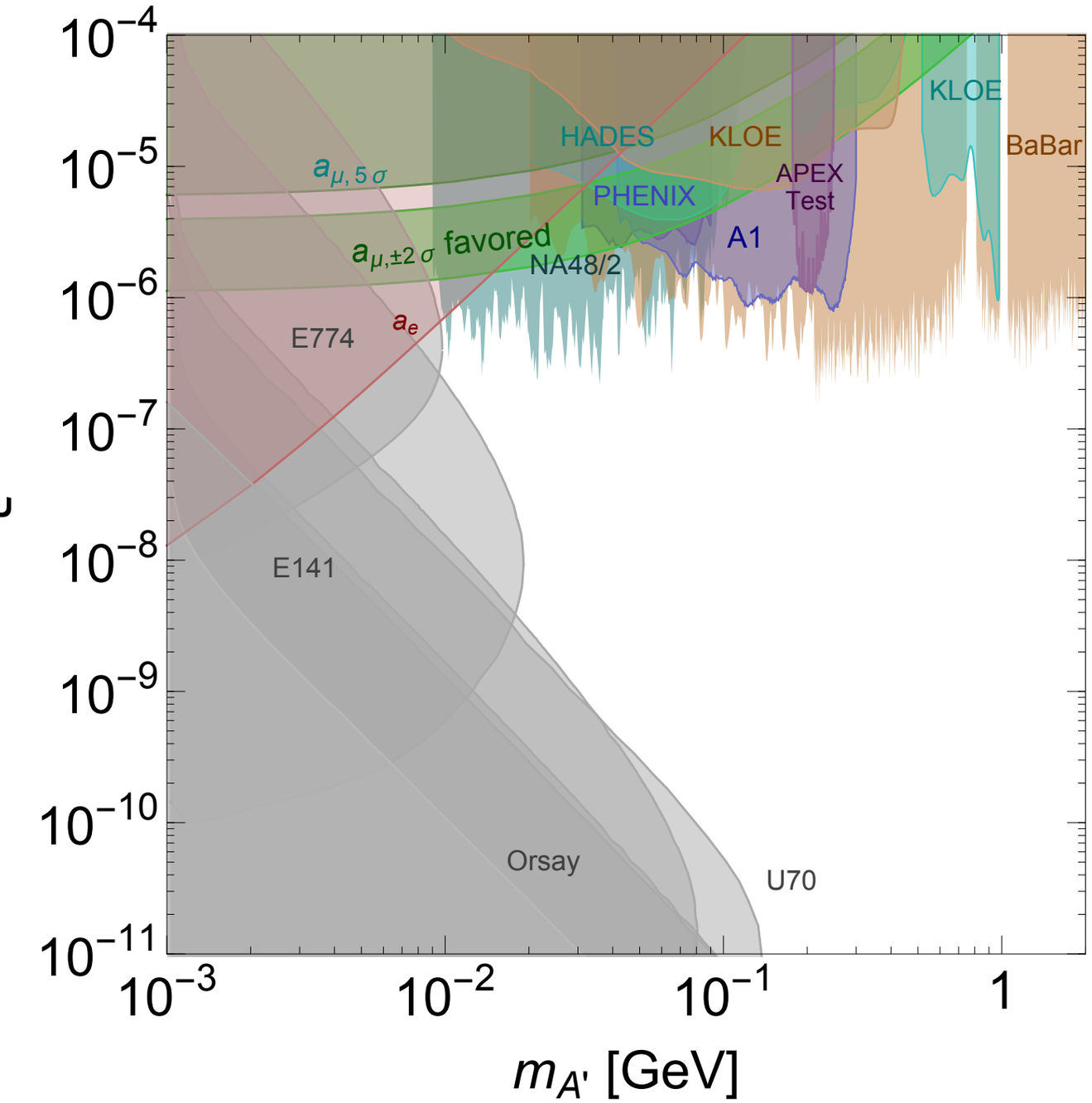


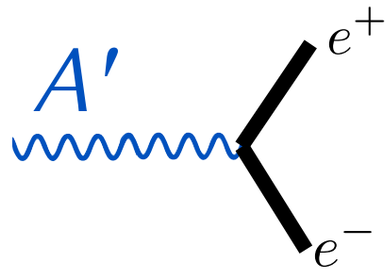
A′ Status 2008



Pospelov; Fayet;

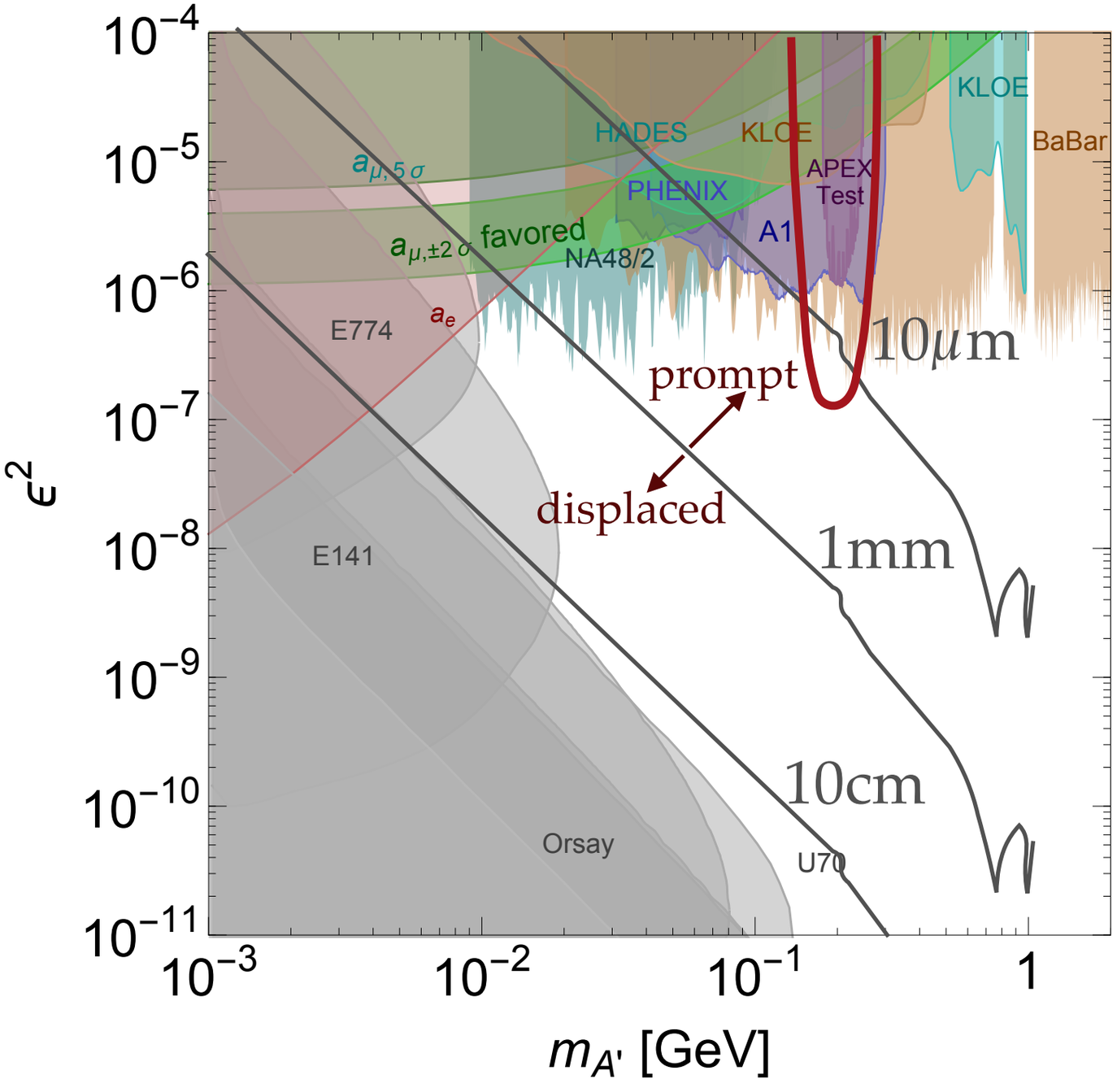
A′ status 2018 (visible)

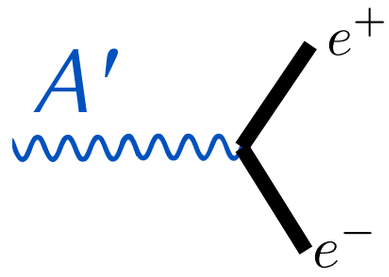




Natural parameter space is illustrated by coupling on y-axis, mediator mass on x-axis.

Visible "Dark Photons"





Red/green: e,μ anomalous dipole moments

All other colors: Pair resonance searches

Gray: Beam Dump

APEX: # of energy settings → breadth of mass coverage (only 2.2 GeV approved for 2019)

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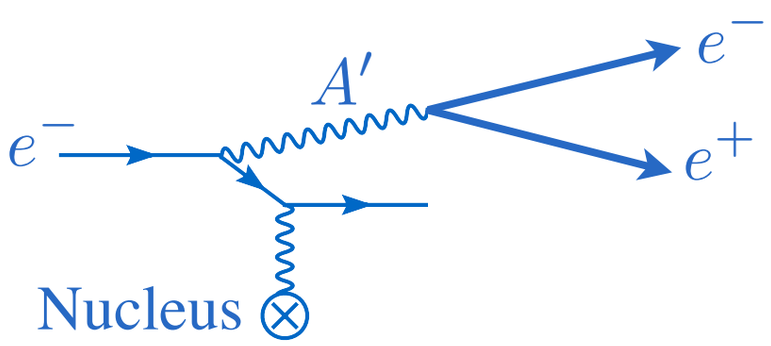
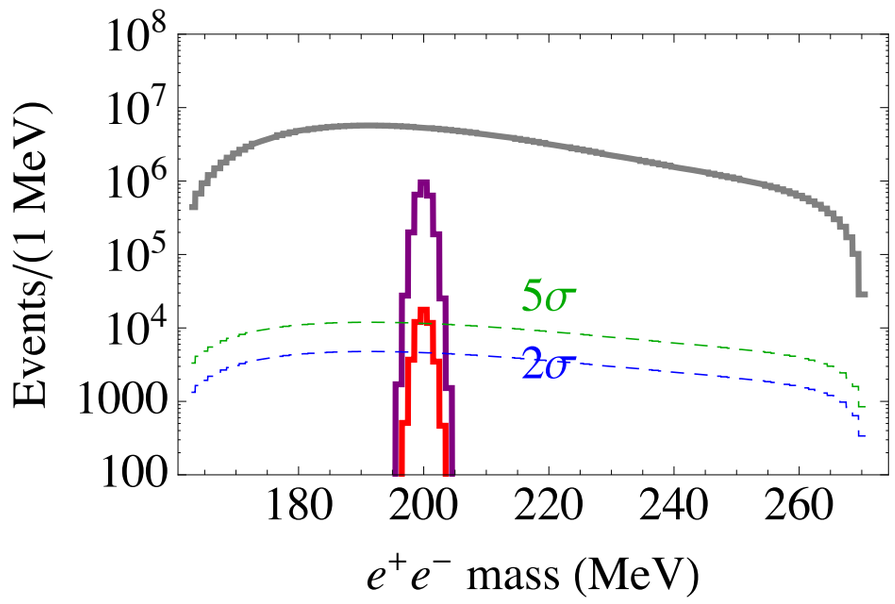
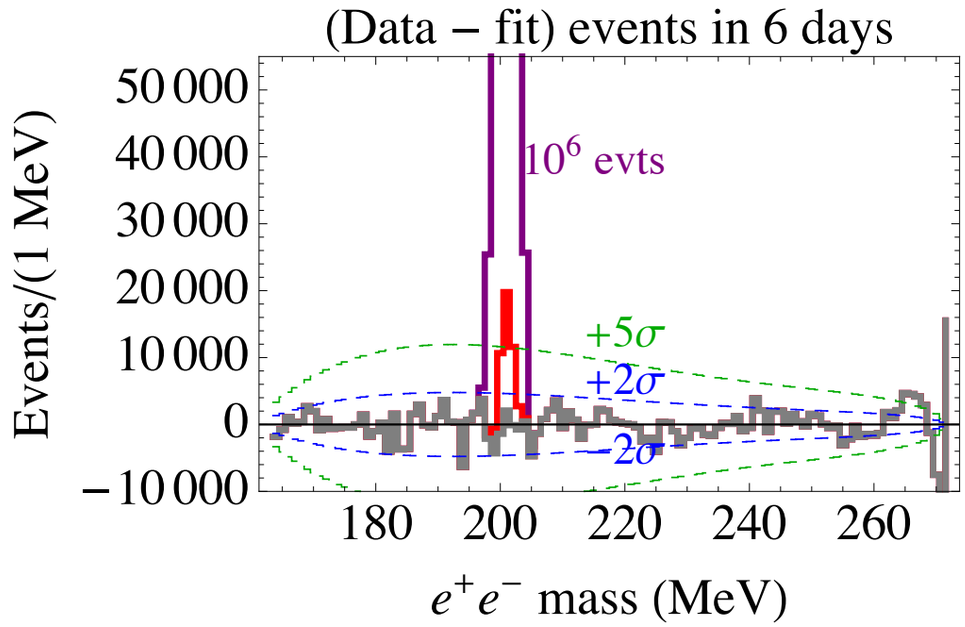


In "prompt" coupling range, key discovery handle is a resonance in e+e– pair mass





High statistics, smooth background & excellent mass resolution → sensitivity to percent-level peaks

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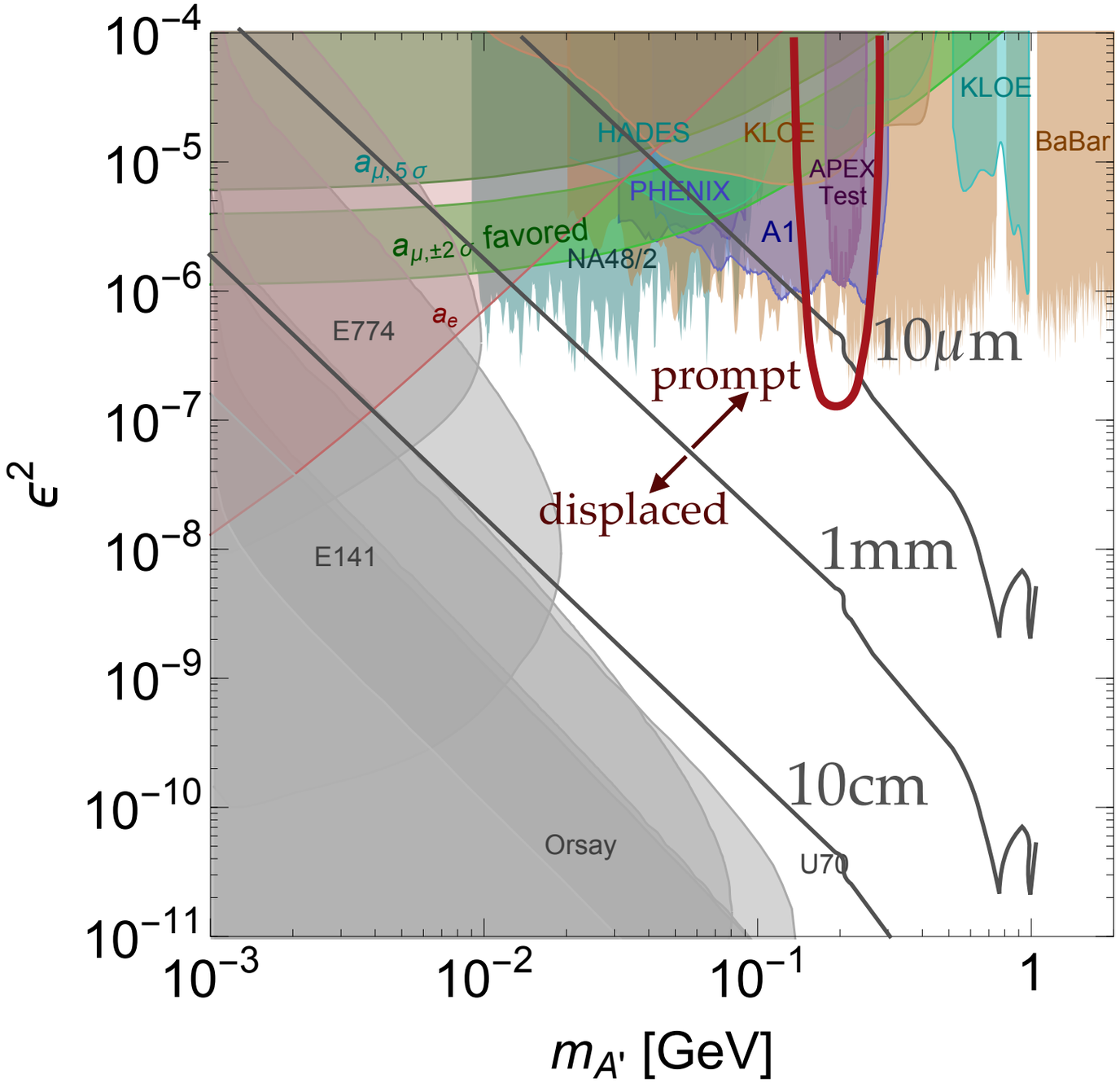

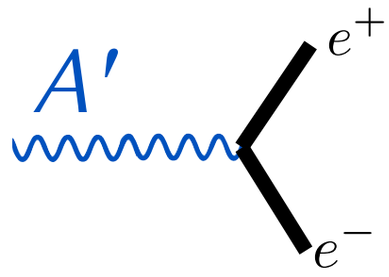

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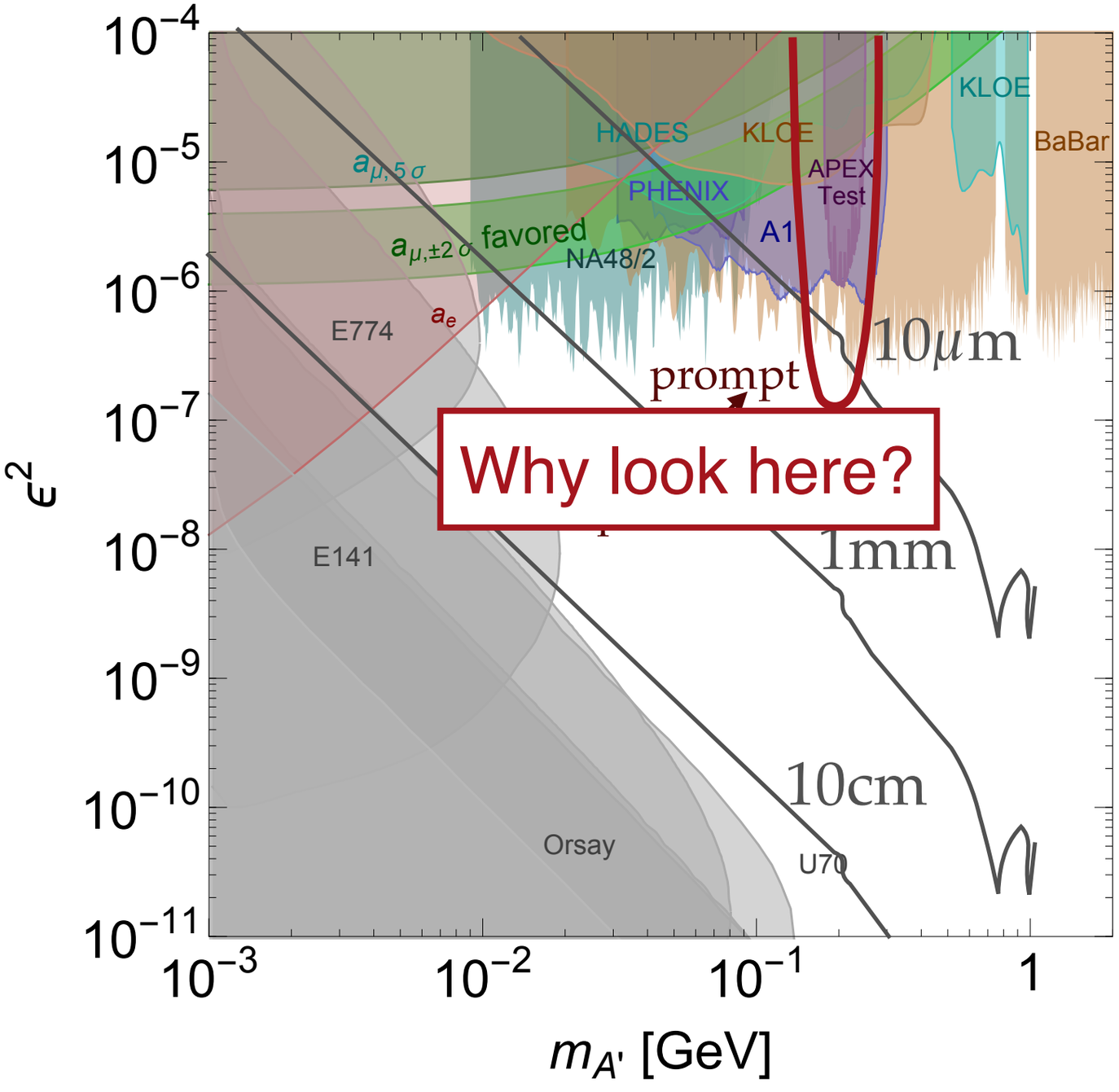

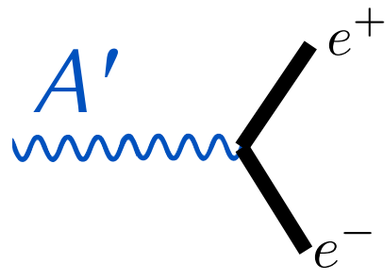

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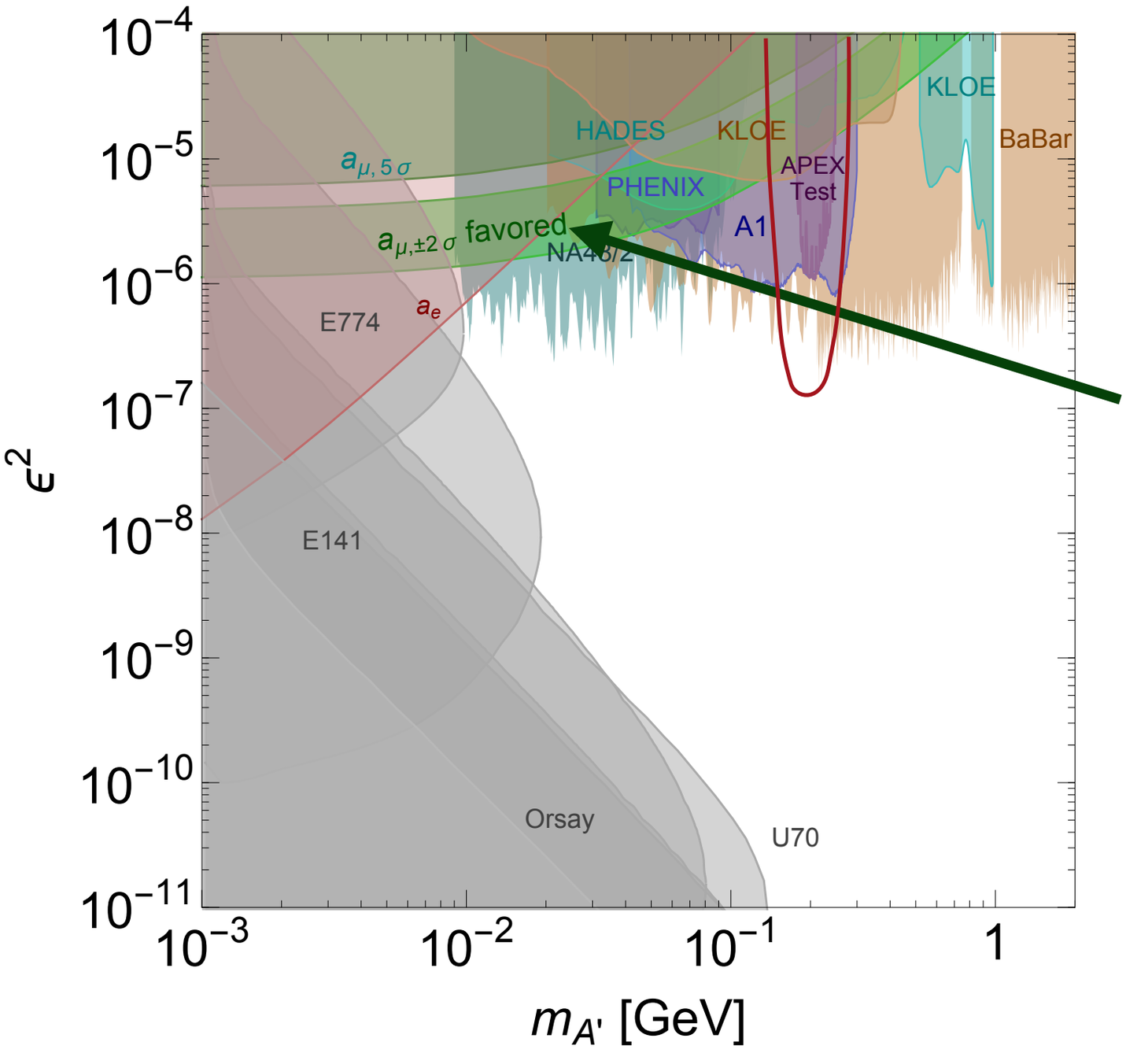
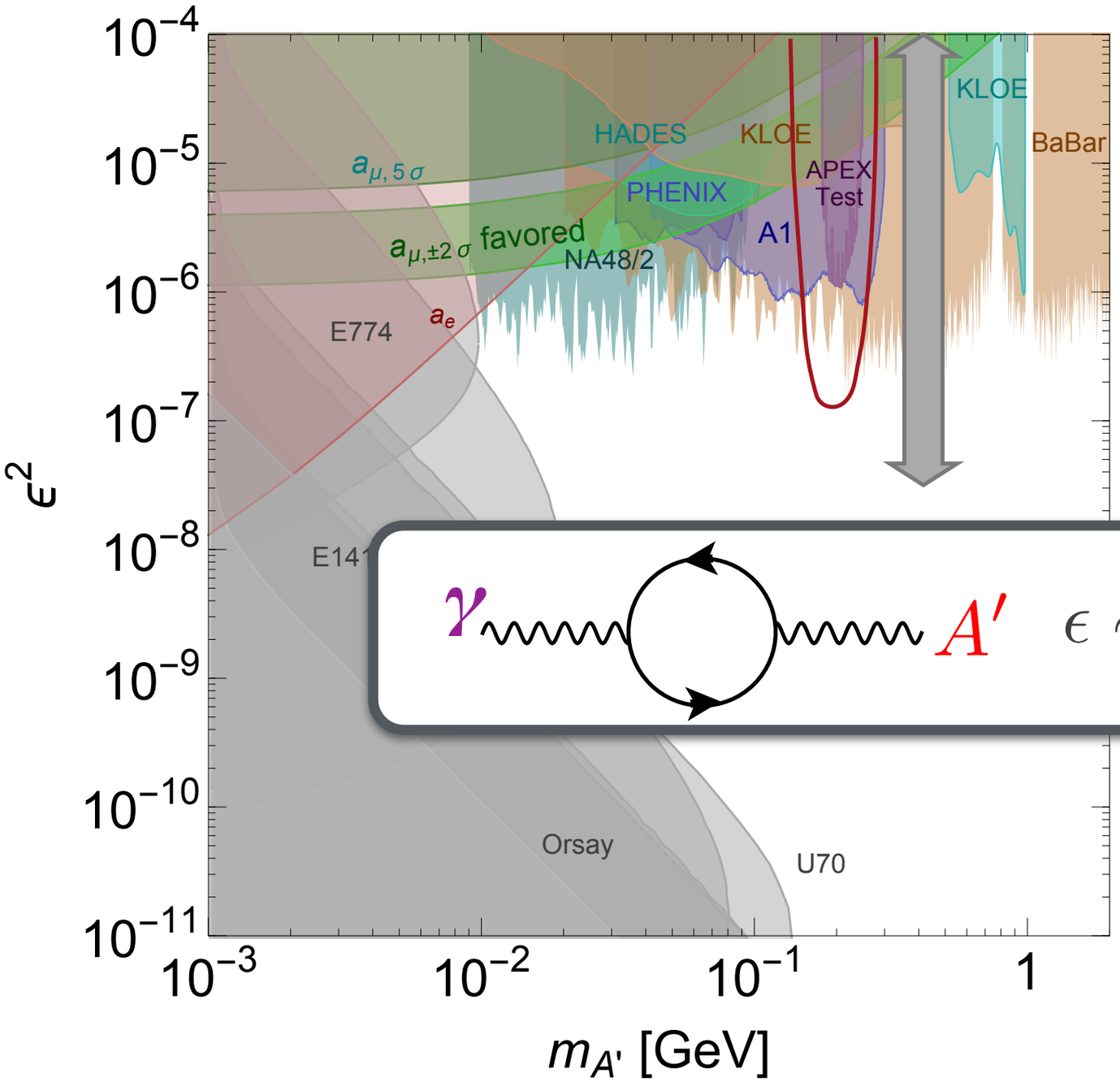
Motivations: Precision Anomalies



Recent accelerator experiments have tested interpretation of muon g-2 anomaly from dark photon

Motivations: Expected Couplings

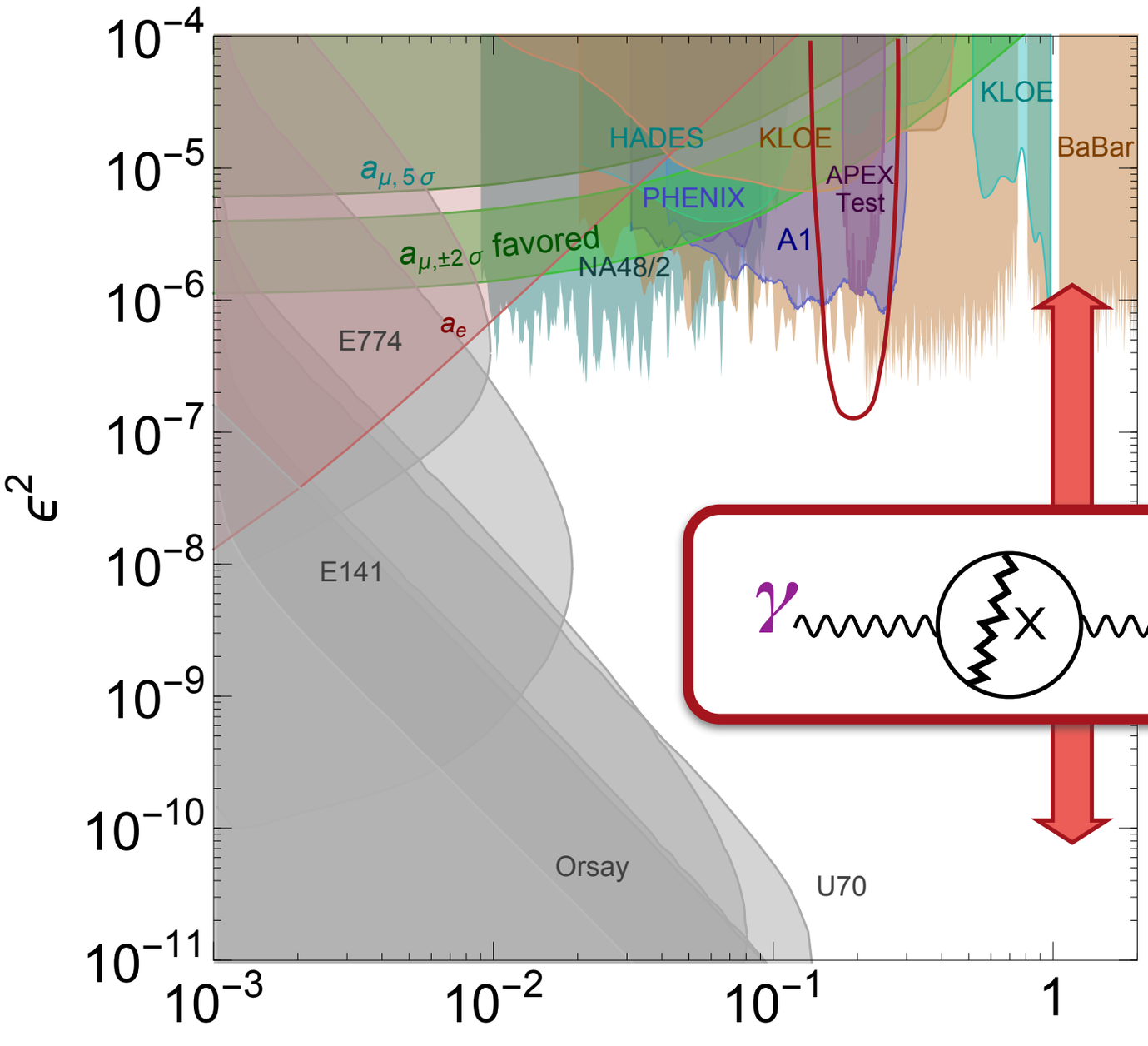


Theoretical expectations:

One-loop radiative corrections?

$$\epsilon \sim \frac{e\, g_D}{16\pi^2} \sim 10^{-2} - 10^{-4}$$

Motivations: Expected Couplings



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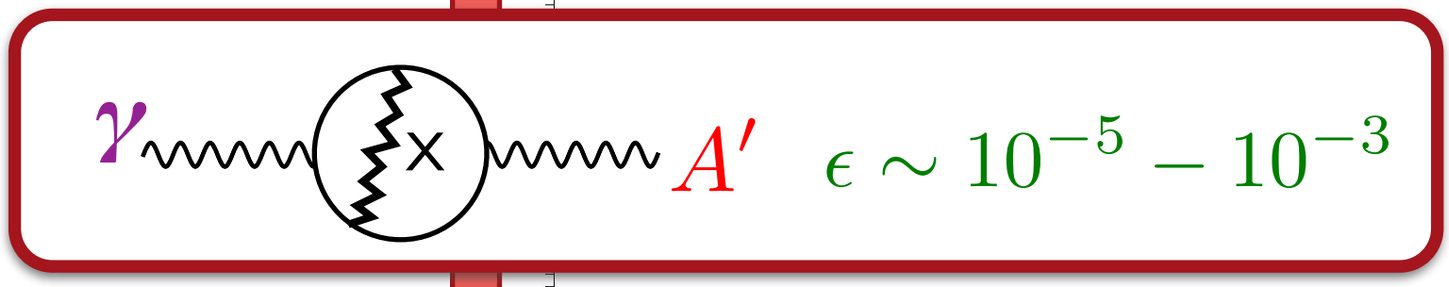
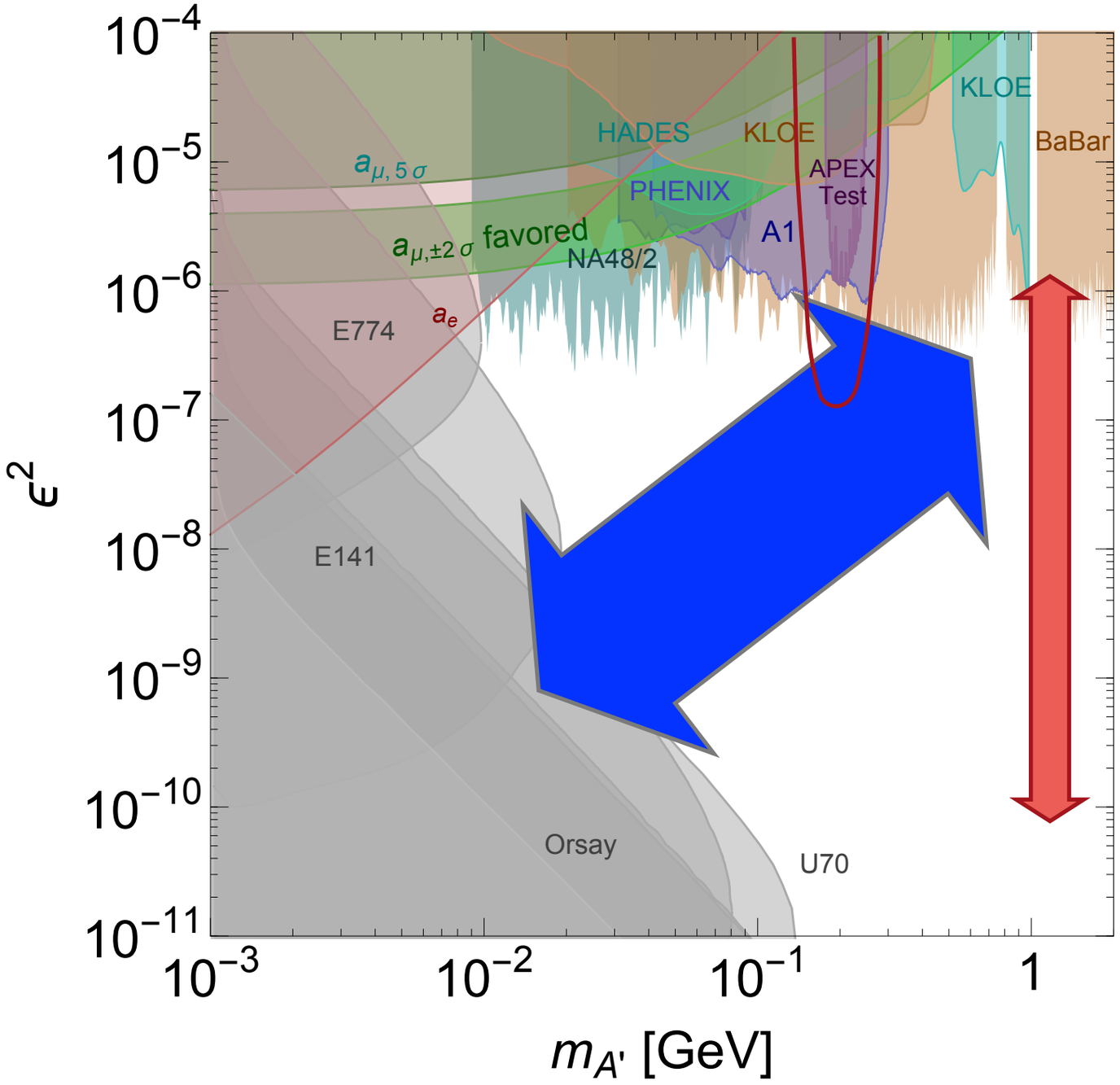
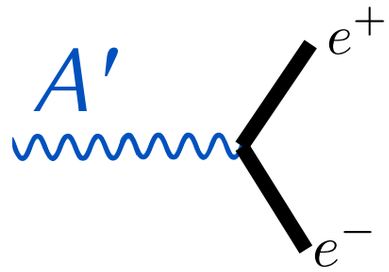


expected in e.g. grand unified theories

APEX takes a significant bite out of this unexplored coupling range!

Motivations: Expected Masses



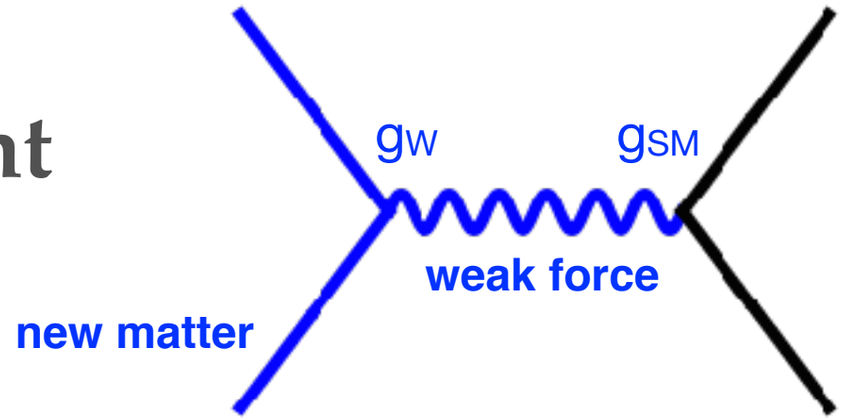


Mixing in Grand Unified Theories

sub-GeV mass scale compatible with ϵ-scale coupling to SM Higgs

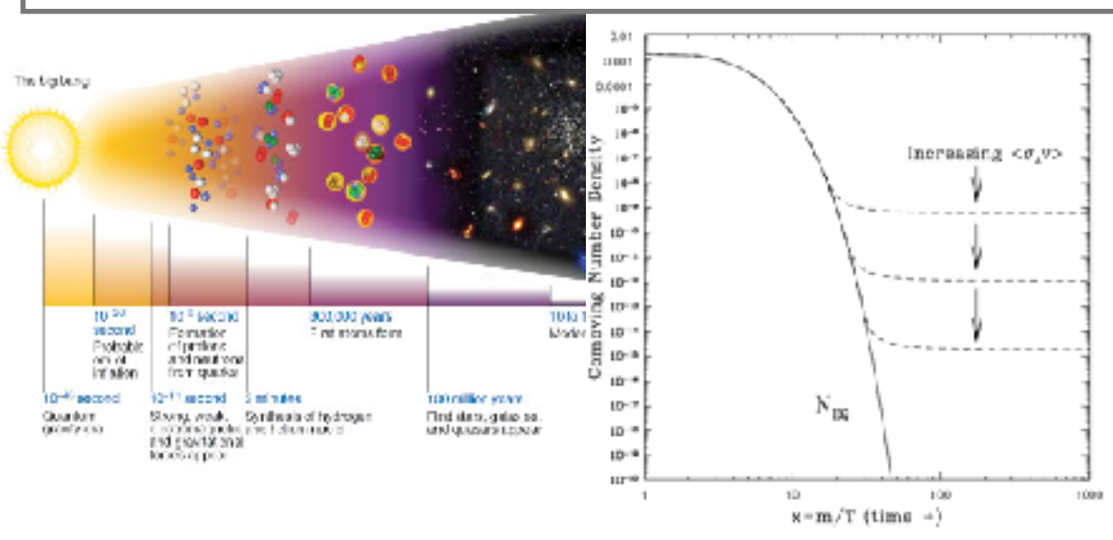
Generalizing WIMPs: Starting Point

Simple, familiar particle content



Simple, predictive cosmology

DM with thermal freeze-out origin

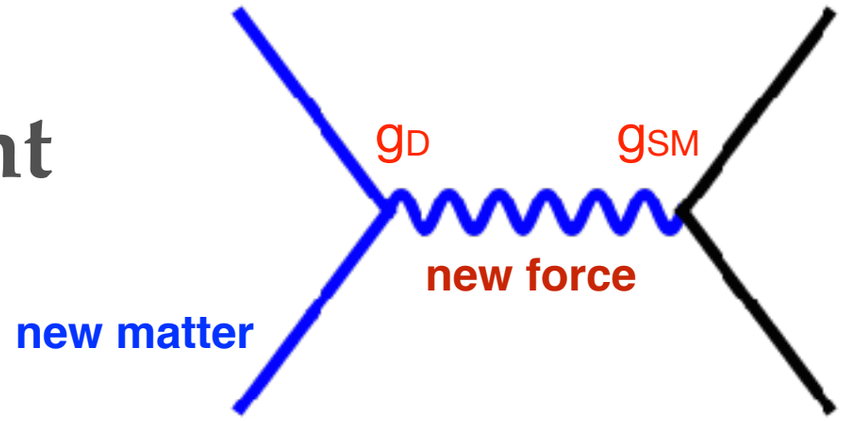


Motivated mass range

WIMP

Generalizing WIMPs: Hidden Sector DM

Simple, familiar particle content



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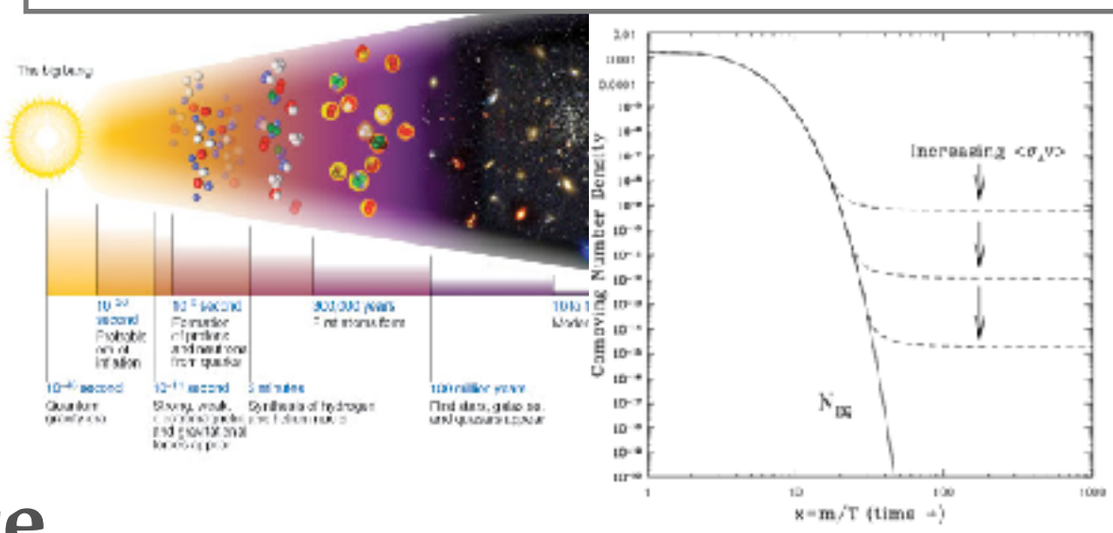
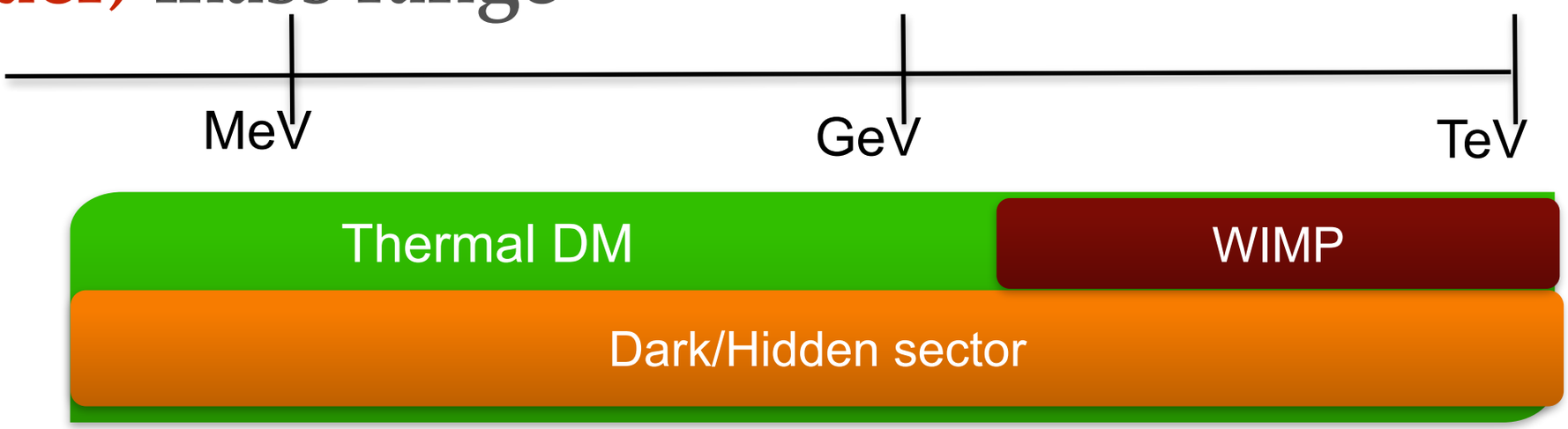
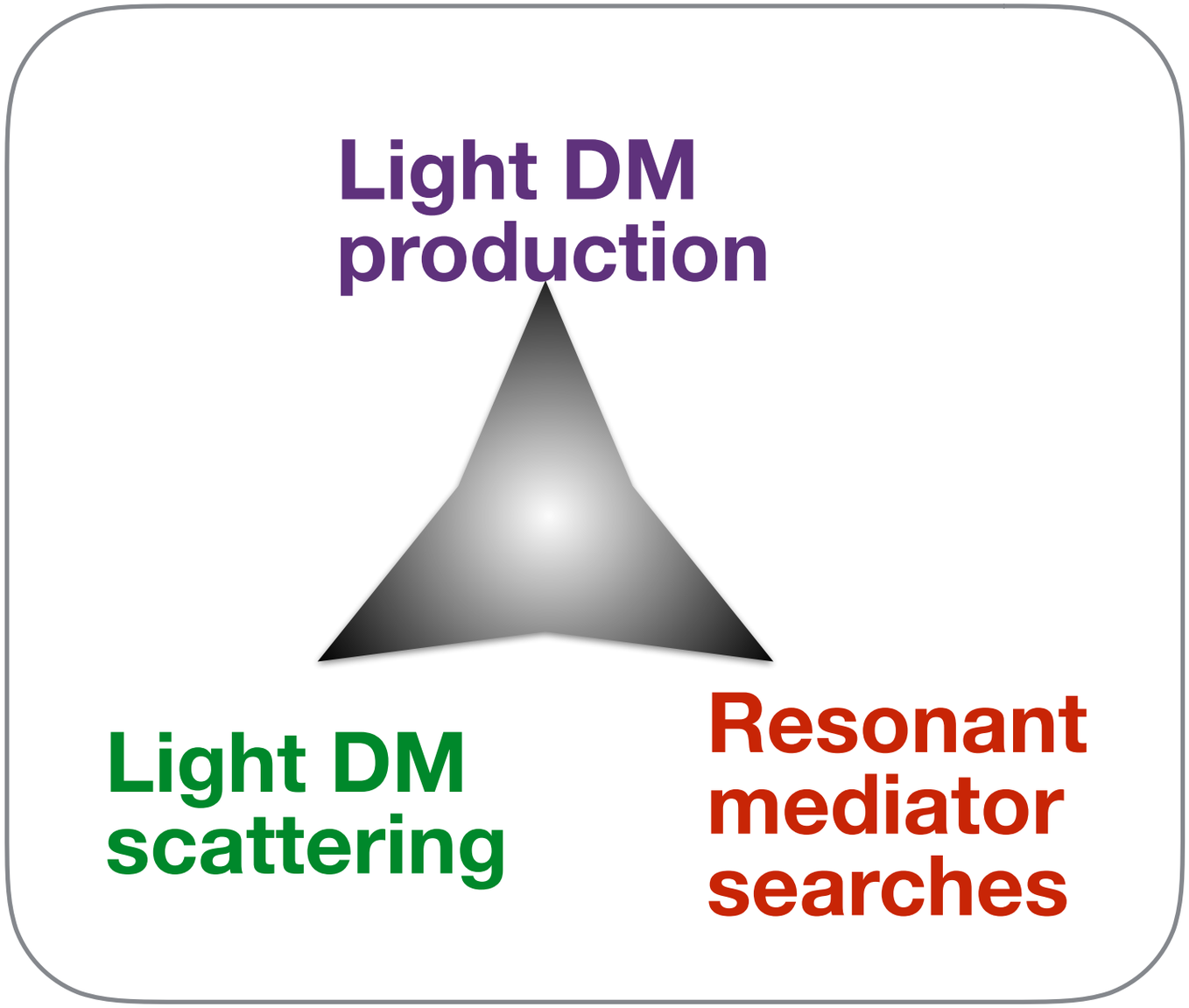


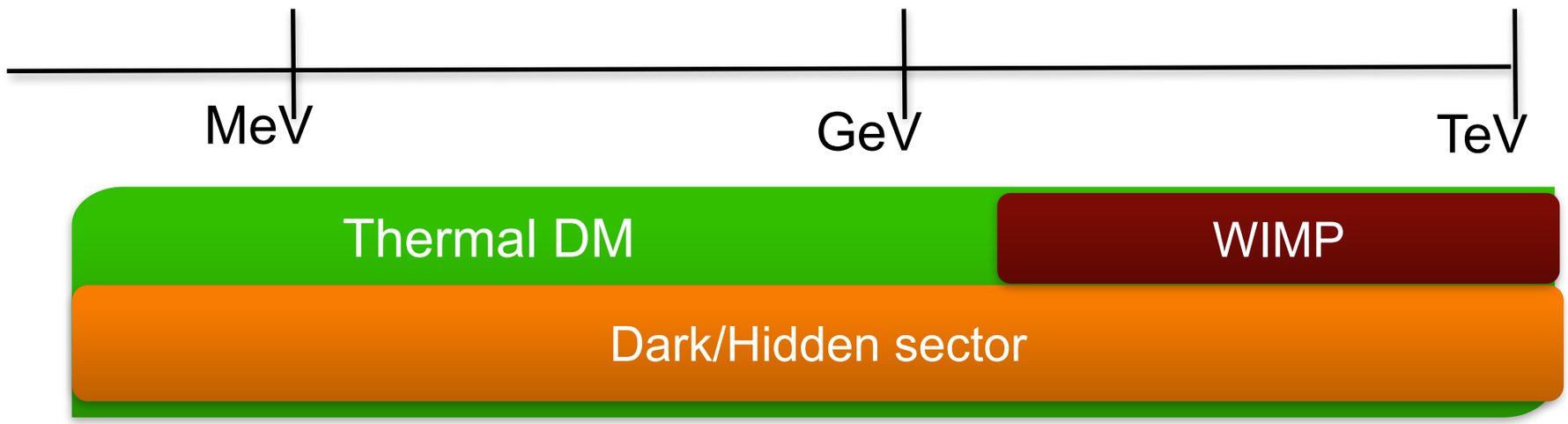
Motivated (broader) mass range



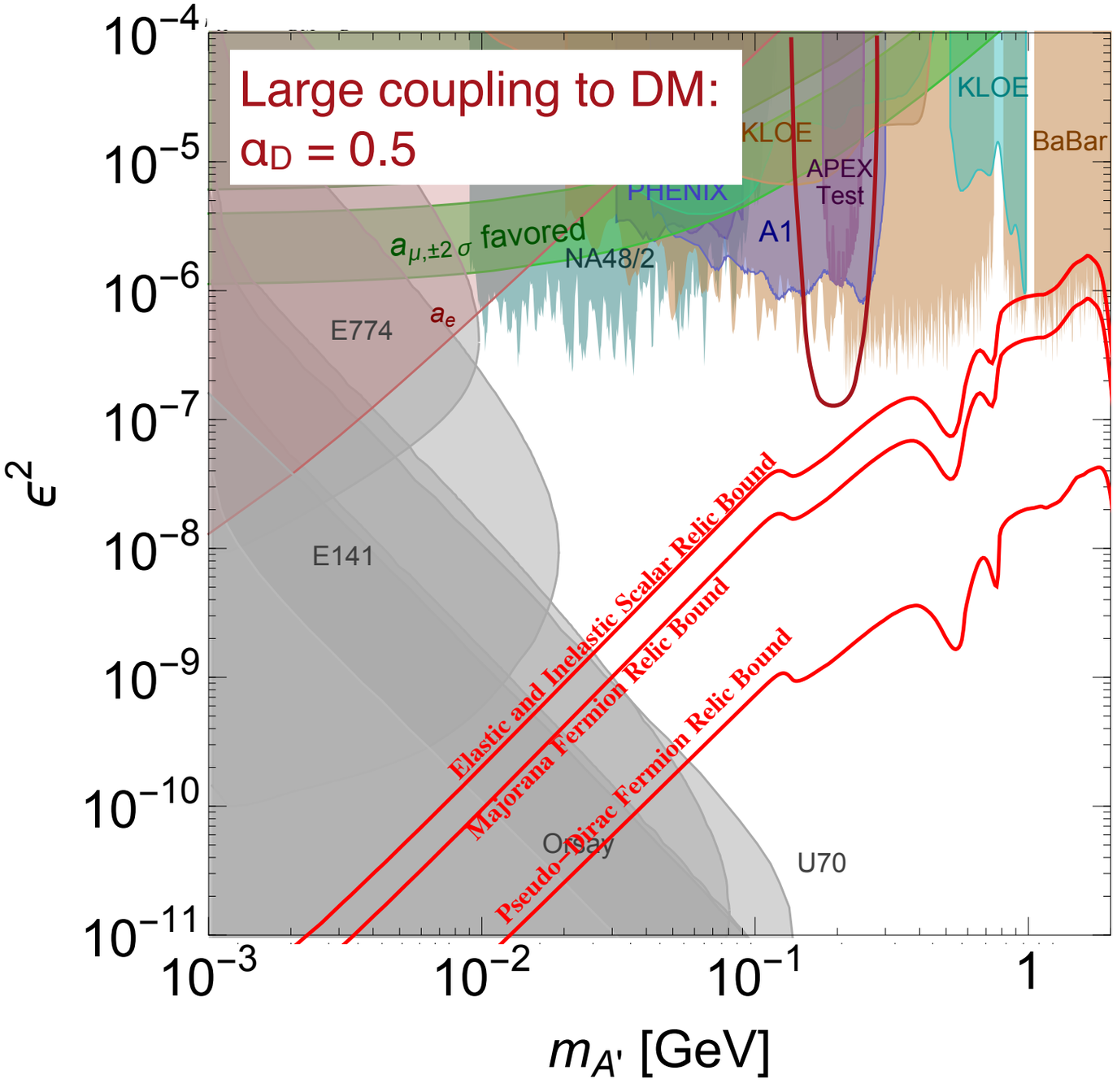
Generalizing WIMPs: Hidden Sector DM

Motivates a portfolio of searches

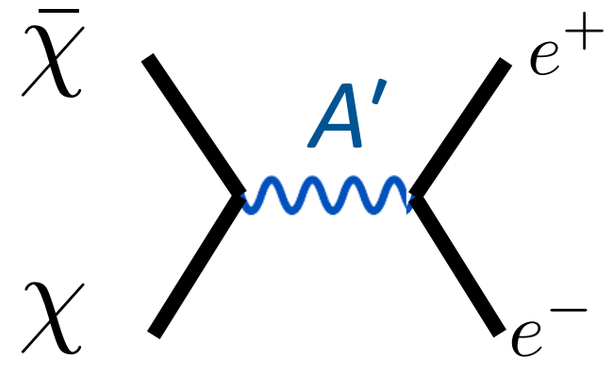




Motivations: Dark Matter Freeze-out



Early universe thermal freeze-out cross-section is constrained by DM abundance

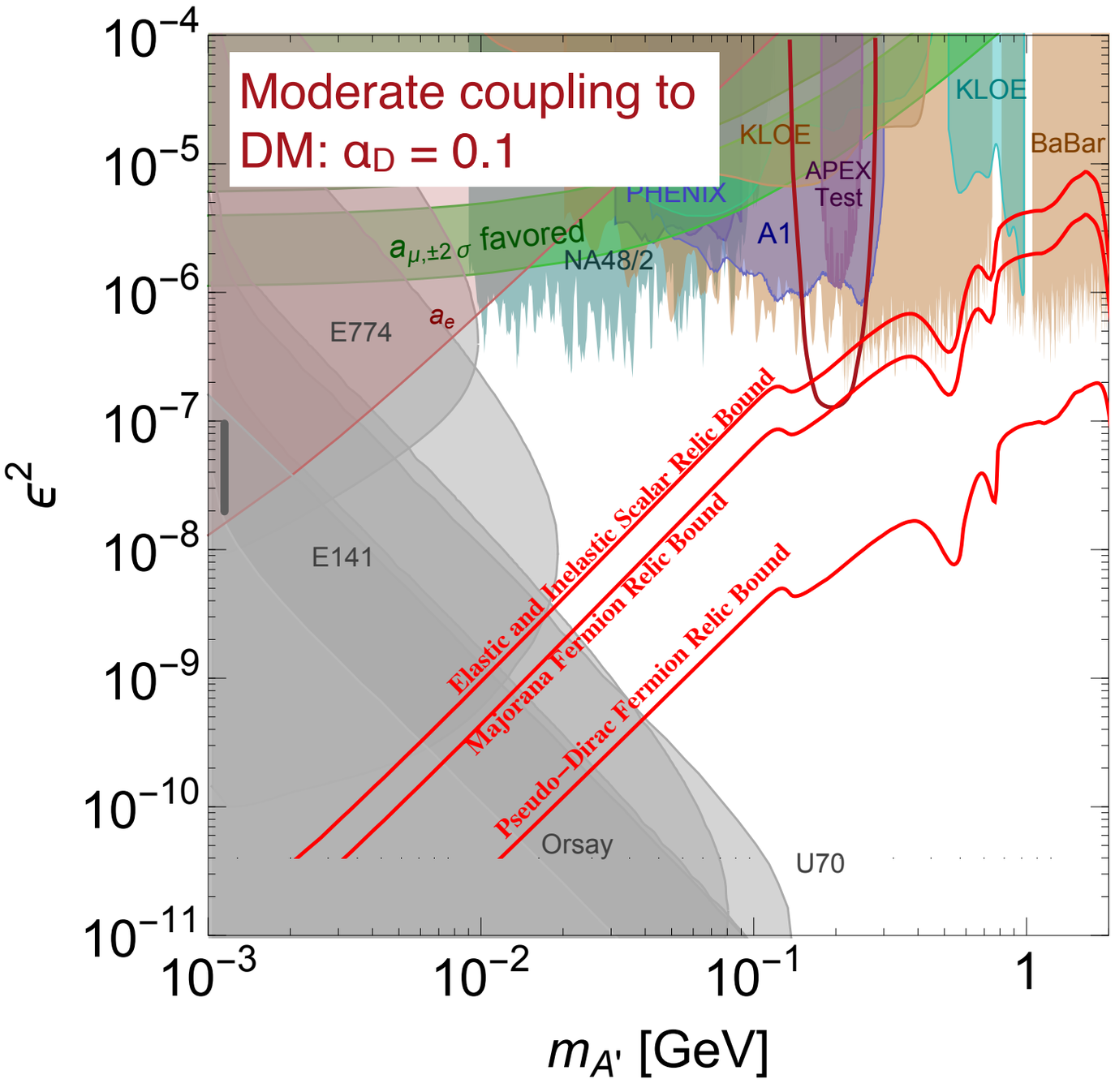


$$\sigma v \sim \alpha_D \epsilon^2 \alpha \times \frac{m_\chi^2}{m_{A'}^4}$$

For part of DM-A' mass range, provides a lower limit on mediator coupling vs mass!

Motivations:
Dark Matter Freeze-out

$m_{A'}=1.3\ m_{\rm DM}$, $\alpha_D=0.5$



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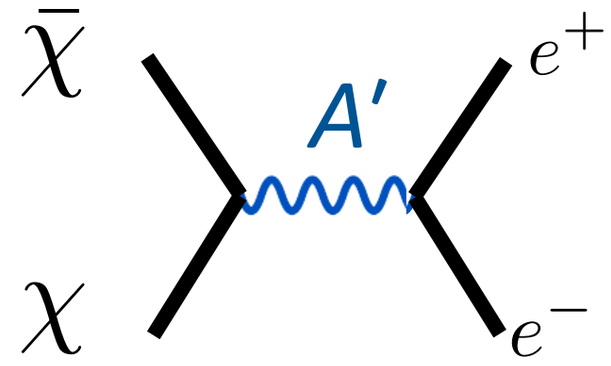

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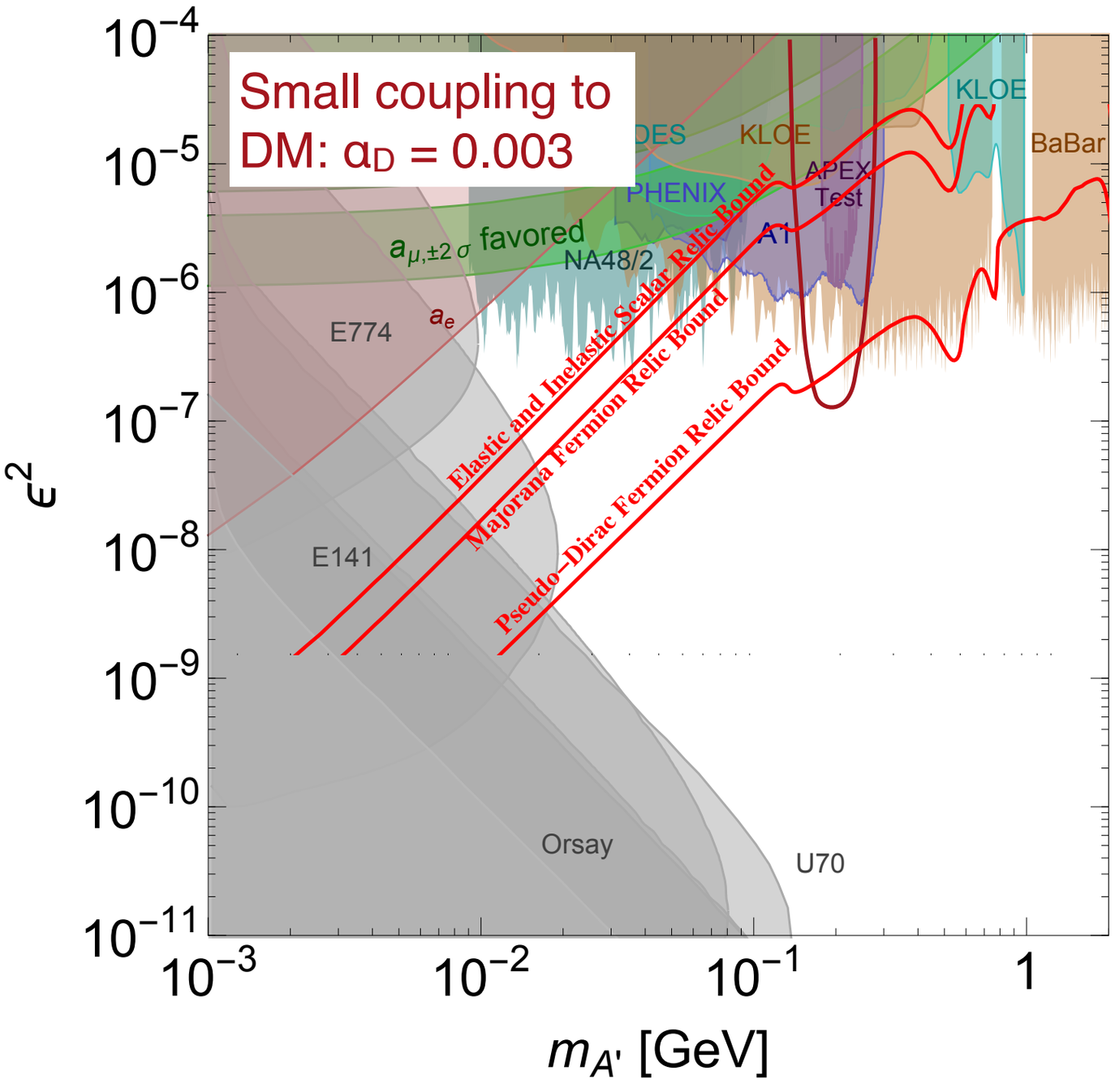
APEX explores interaction strengths consistent with thermal freeze-out of light DM

Motivations: Dark Matter Freeze-out



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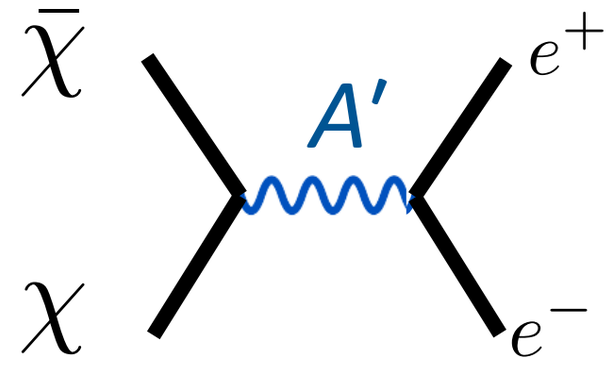

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APEX explores interaction strengths consistent with thermal freeze-out of light DM

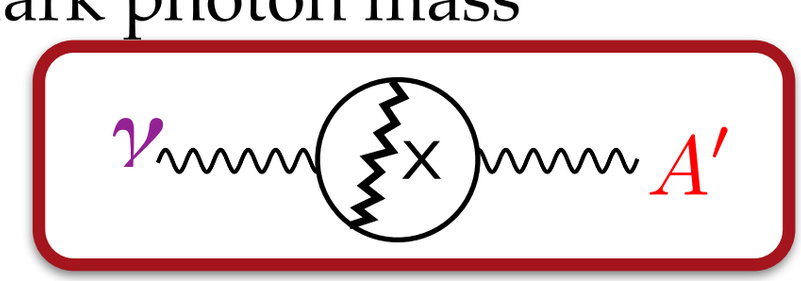
Conclusions

Exciting discovery physics at the weak-coupling, low-mass frontier!

"Dark photon" coupled to EM charges is a generic signal of SM-neutral new physics and important benchmark model

APEX explores significant and motivated parameter space

- Theoretical expectations for mixing strength and (less sharply) dark photon mass



- Dark-matter-motivated milestones