Tabletop Experiments for HEP

Peter W. Graham

P5 Townhall 3/20/23

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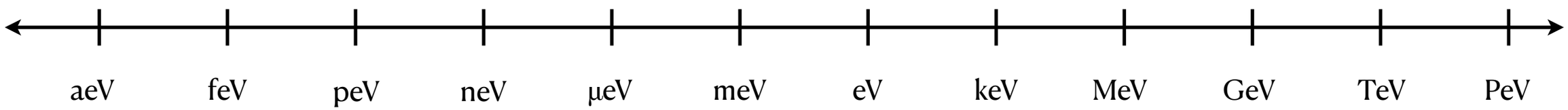
Tabletop Experiments for HEP

Wide variety of experiments covering physics spanning large energy range:



This area has exploded in the past decade, now a large community.

I could not possibly cover it all, will pick a few examples, but many more great possibilities!

In each case will focus on physics reach, not specific experiments.

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Outline

1. Standard Model (SM) measurements

   - EDMs, e^- g-2, α...

2. Dark Matter Direct Detection

   - QCD axion, light DM, axions, dark photons ...

3. 5th Forces and New Light Particle Production

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Precision Measurement of the Standard Model

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Electric Dipole Moments (EDMs)

- Arises from CP violation, but observable CP effects suppressed in SM
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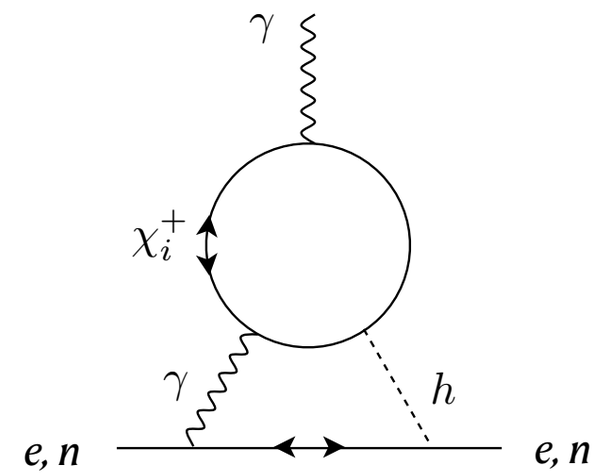

hep-ph/0510197

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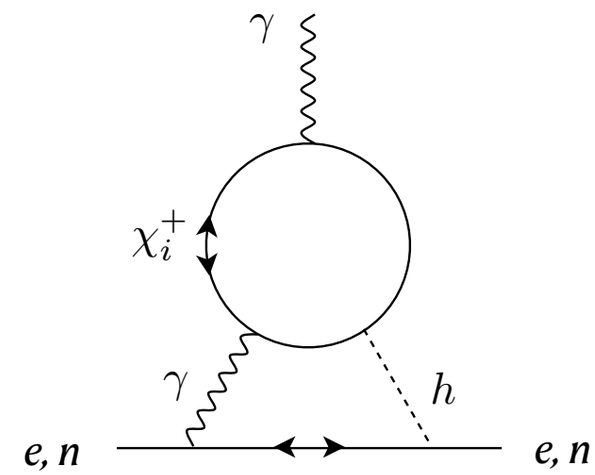

hep-ph/0510197

- Can be searched for in a variety of nuclei, atoms, and molecules using high precision techniques e.g. from AMO
- So is an excellent channel to search for new particles

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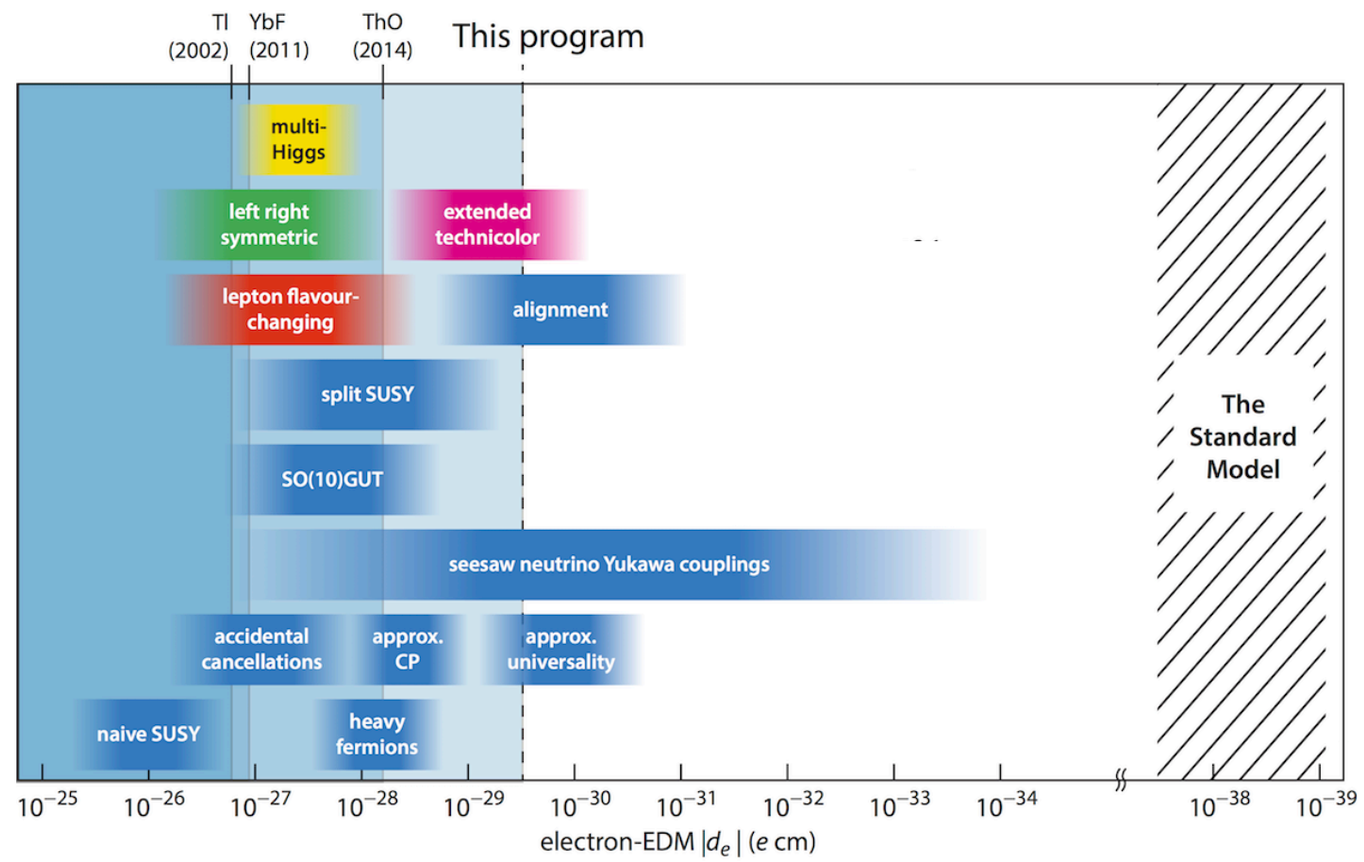
EDMs for BSM Physics

- Many theories give EDM's



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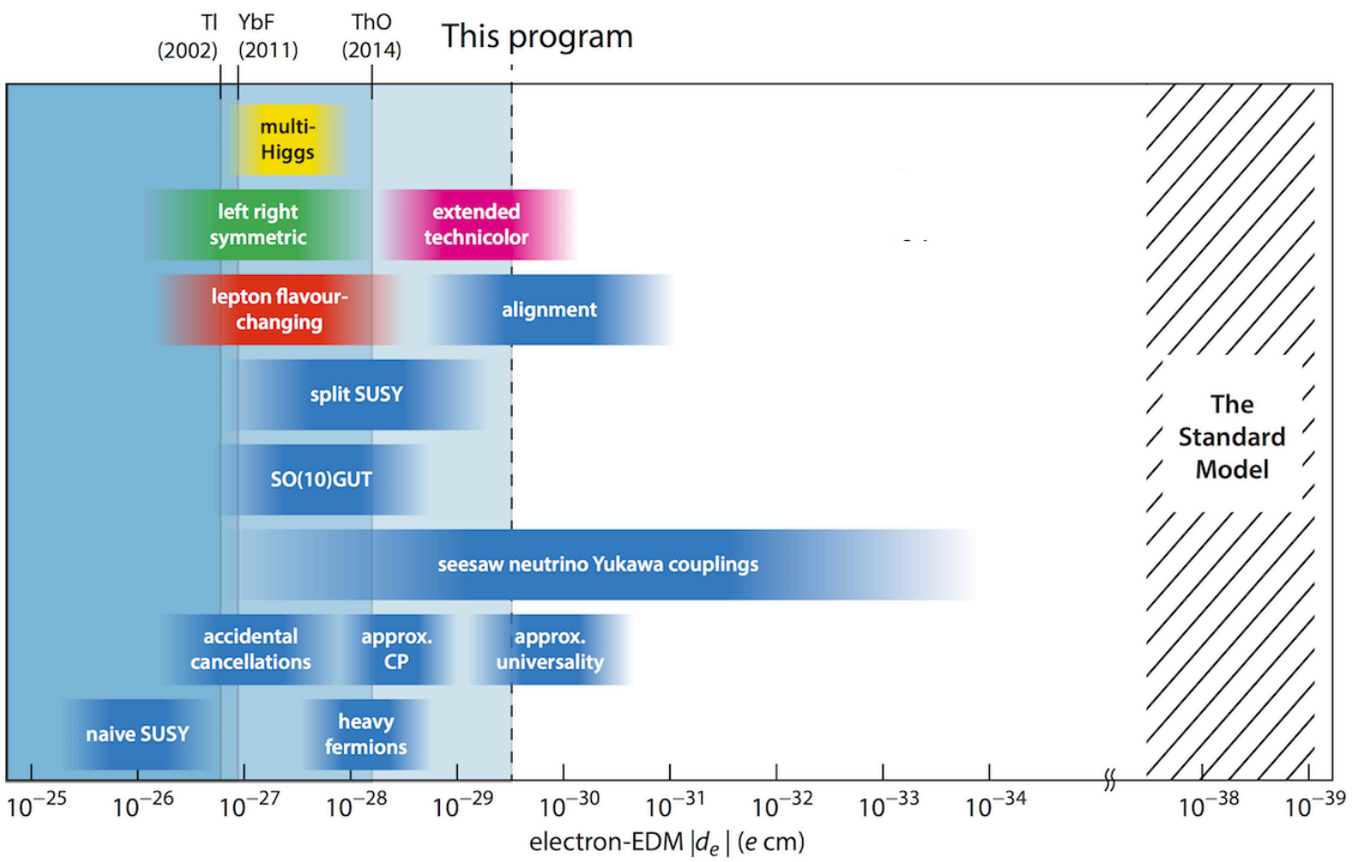

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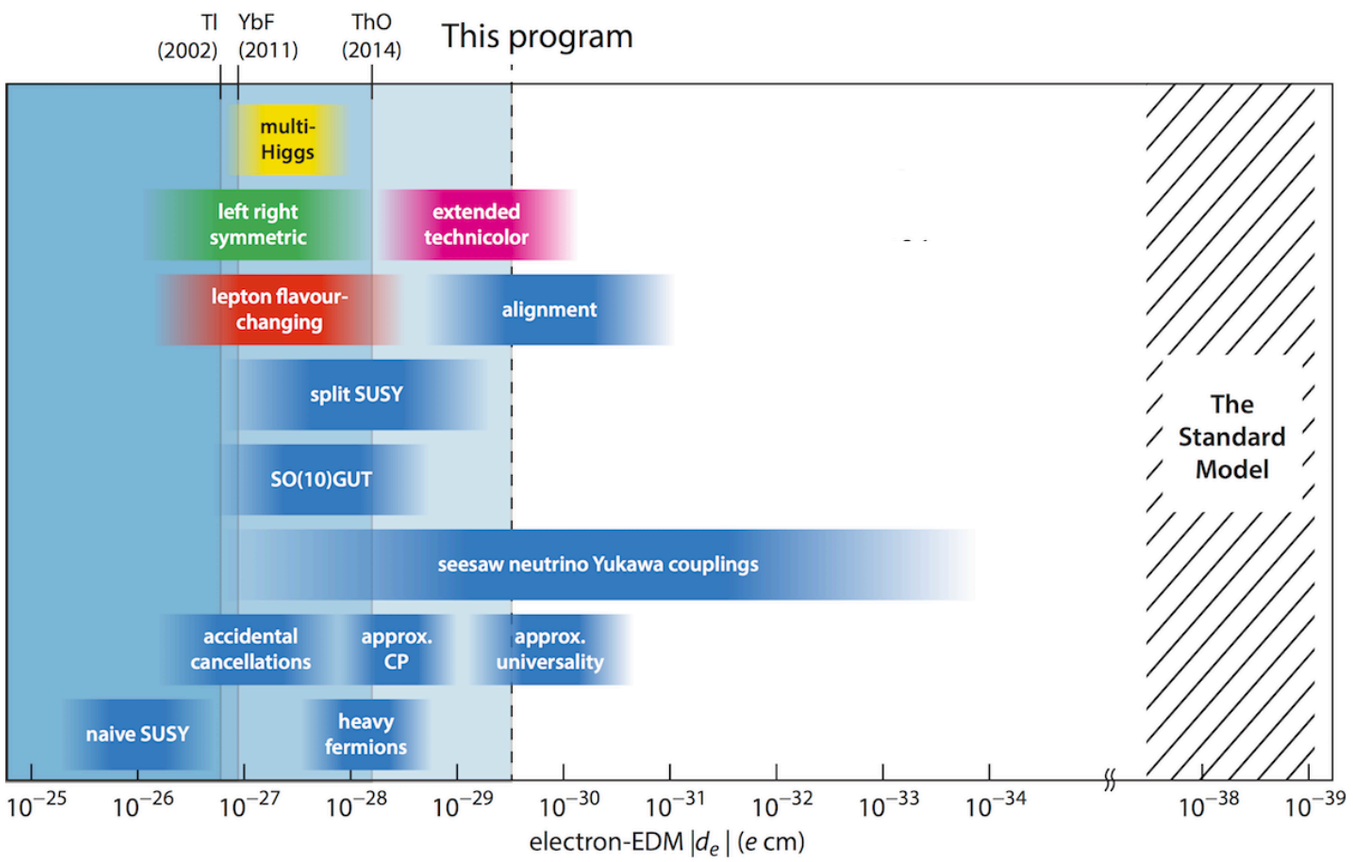

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- Even non-observation is important, limits many theories and e.g. nEDM bound → Strong CP problem (axion etc)

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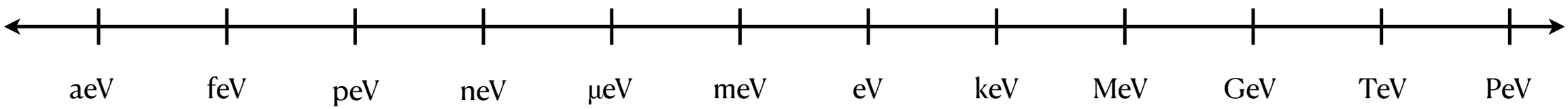
EDM Experiments



Experiments made fantastic progress, set strong limits on e and n EDMs

$$d_e < 4.1 \times 10^{-30}\, e\,\mathrm{cm}$$

From HfF^+ 2212.11841

$$d_n < 1.8 \times 10^{-26}\, e\,\mathrm{cm}$$

From UCN 2001.11966

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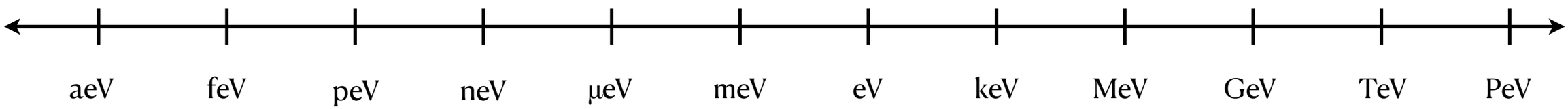
EDM Experiments



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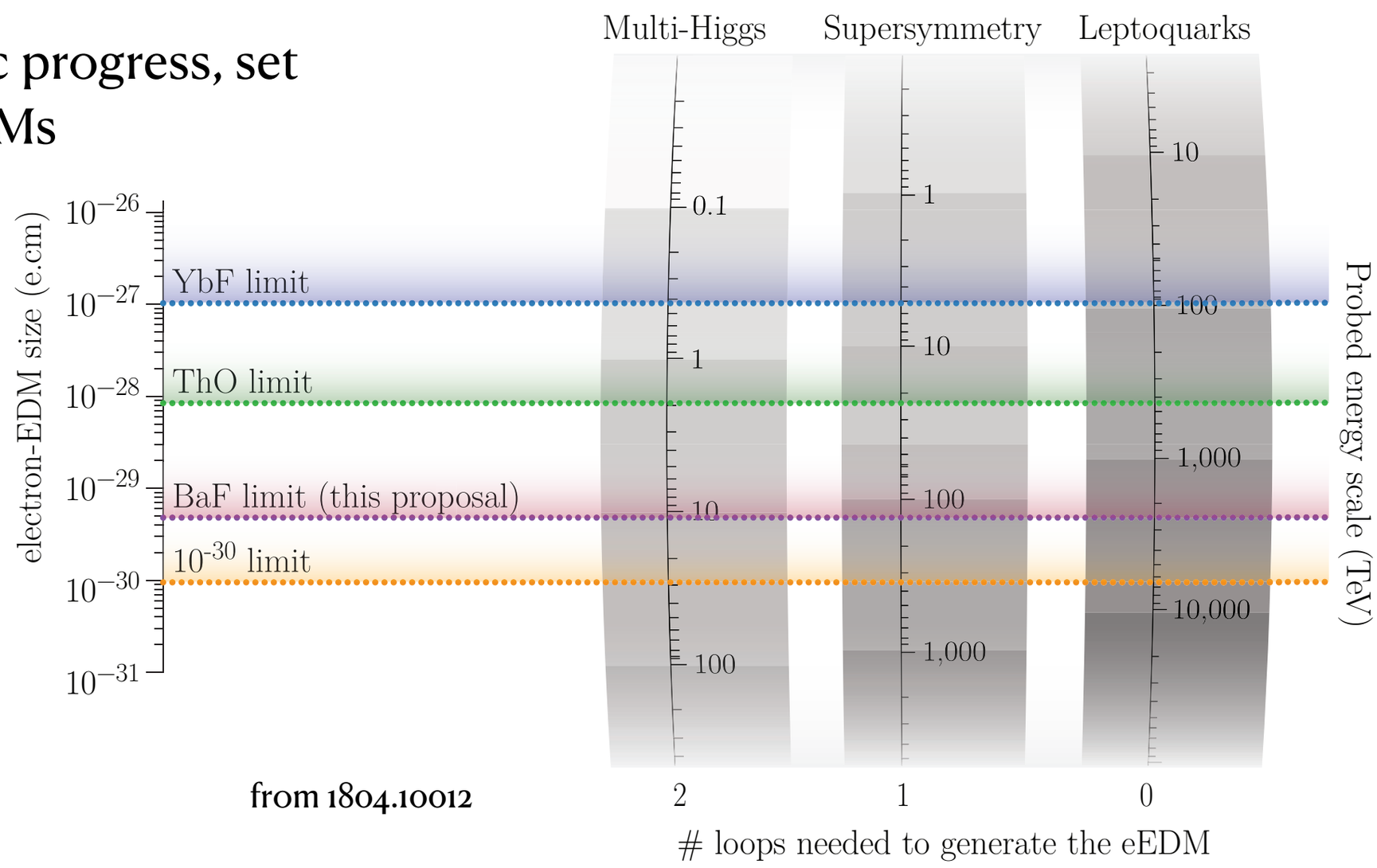

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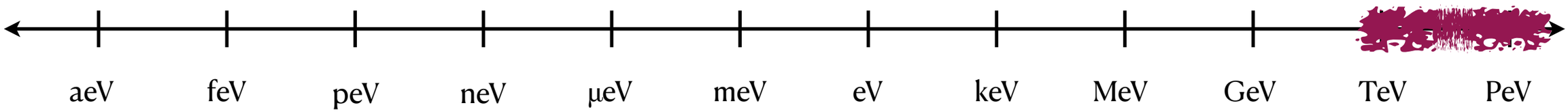
EDM Experiments



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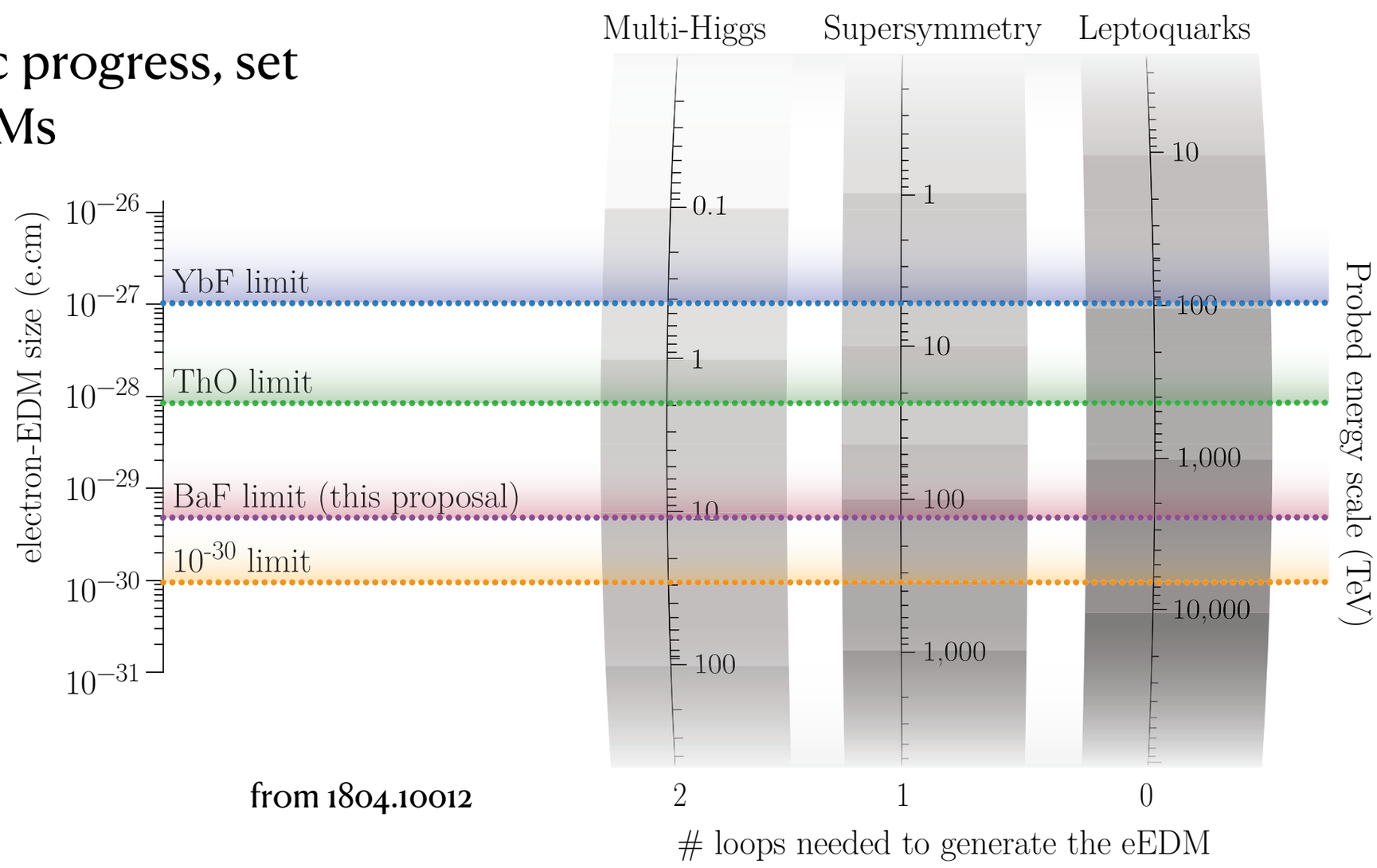

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Many new proposed experiments poised to improve bounds significantly

Probes energy scales far above LHC reach

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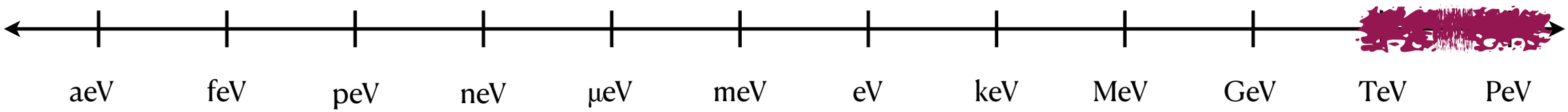
EDM Experiments



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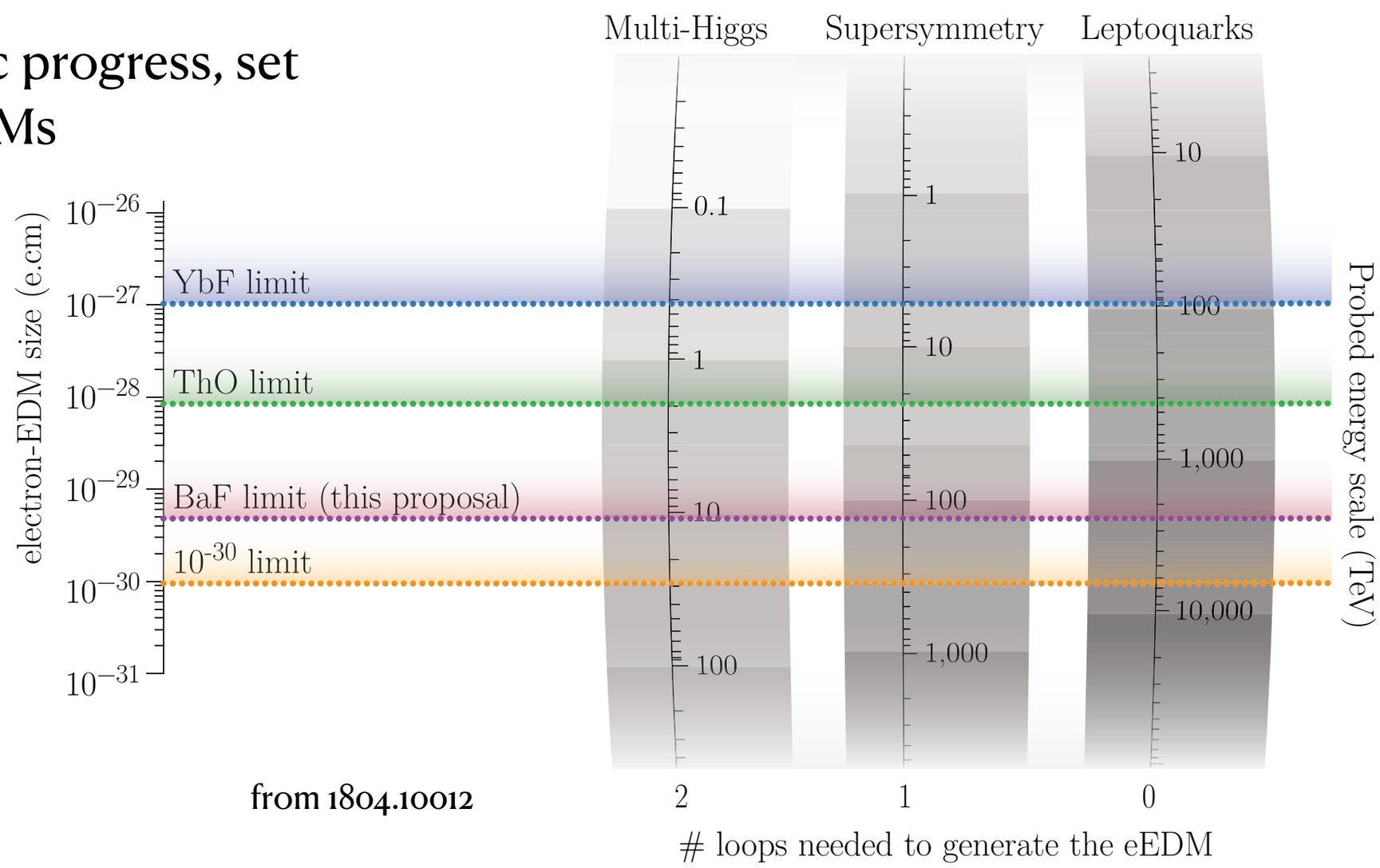

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Many other precision SM measurements probe BSM physics, e.g. e^- g-2, α...

Dark Matter Direct Detection

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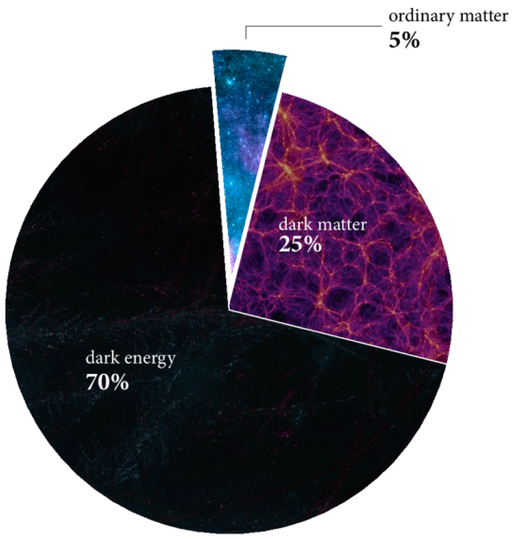
Dark Matter

Dark matter is an extremely important avenue for searching for new physics

It is most of the matter in the universe,

responsible for galaxies/structure.

And is definitely not in the SM



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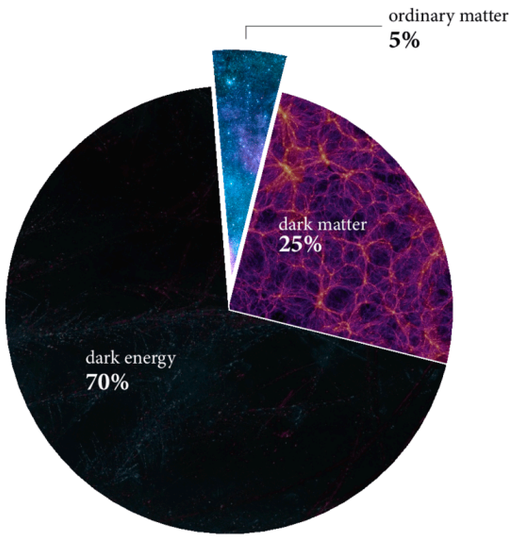

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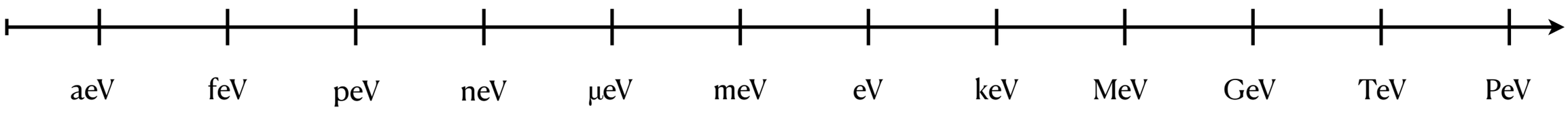
Recent rapid growth in direct detection ideas/experiments *across entire mass range*



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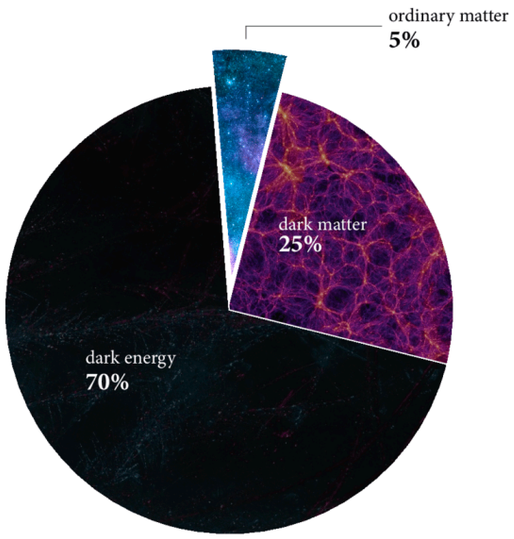

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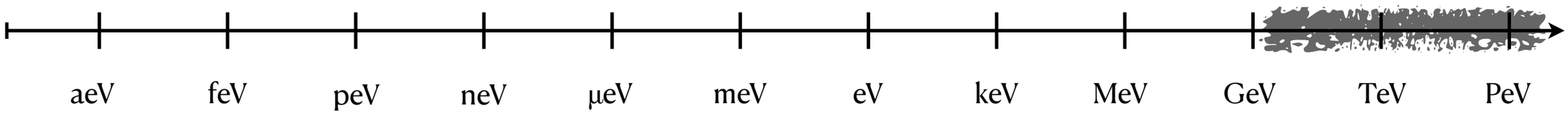

"WIMP" detectors

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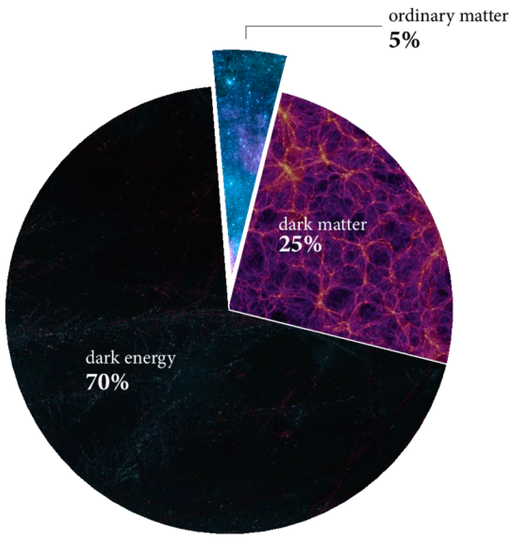

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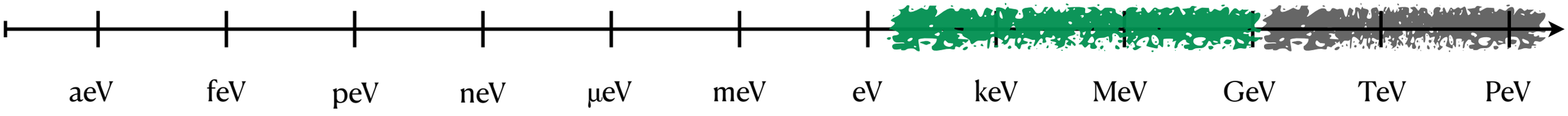

Light DM ("particle-like") "WIMP" detectors

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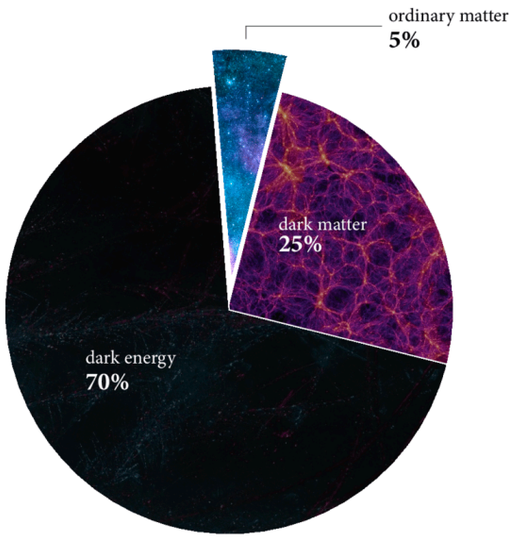

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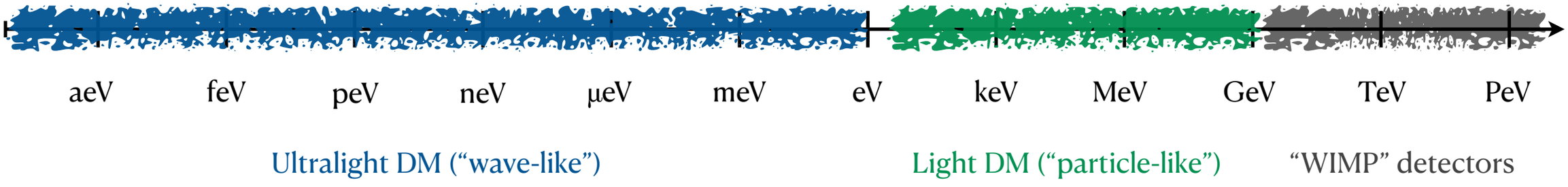

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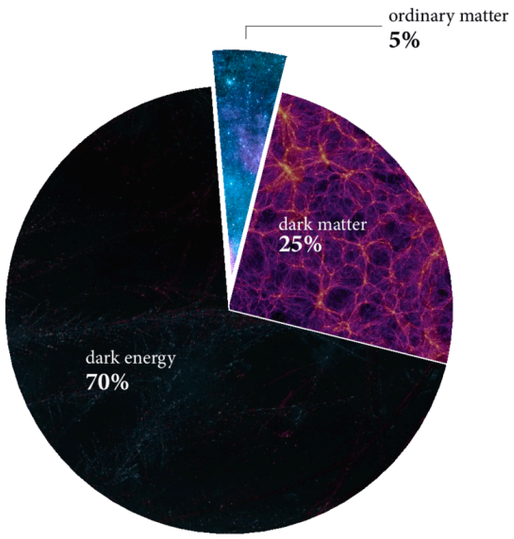

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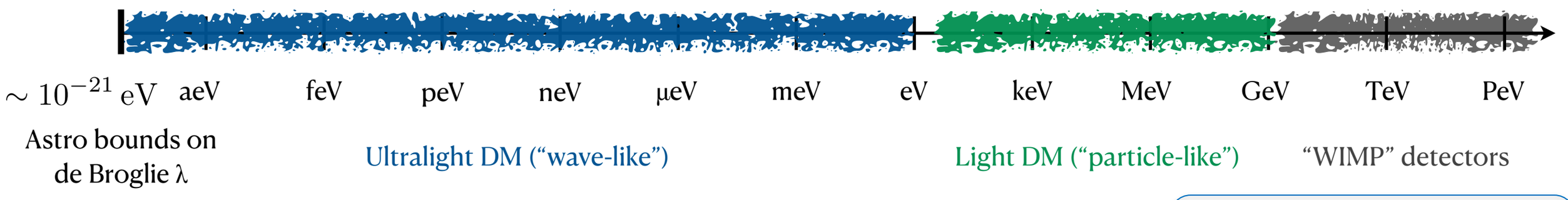

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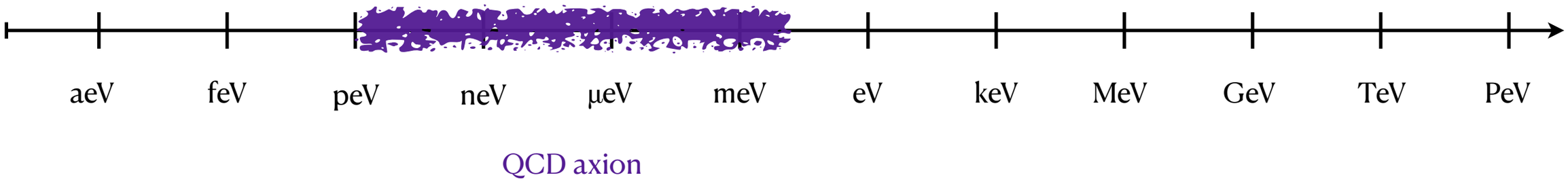
QCD Axion



QCD axion is strongly theoretically motivated

- solution to Strong CP problem
- naturally makes dark matter
- generic in UV (e.g. string) theories

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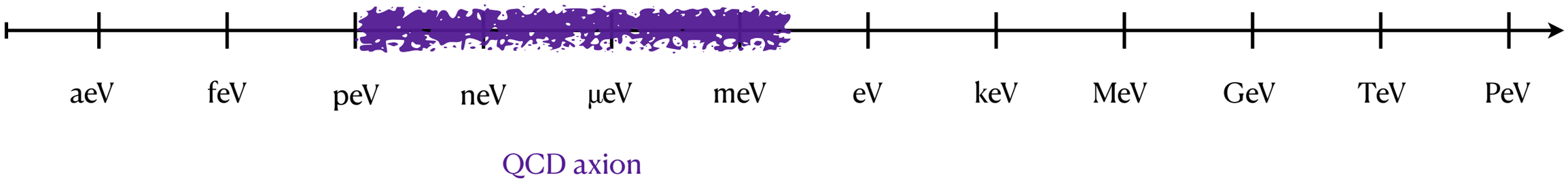

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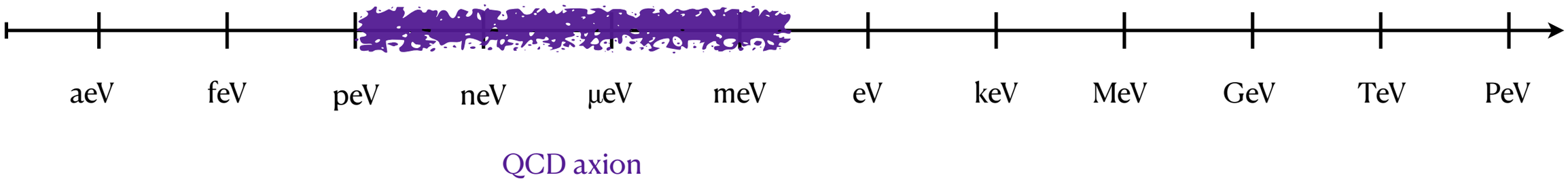

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Arises from ultra-high energy physics:

A detection and measurement of couplings (e.g. to EM, QCD, e^-, n, p) probes physics at these scales, far beyond what colliders can reach

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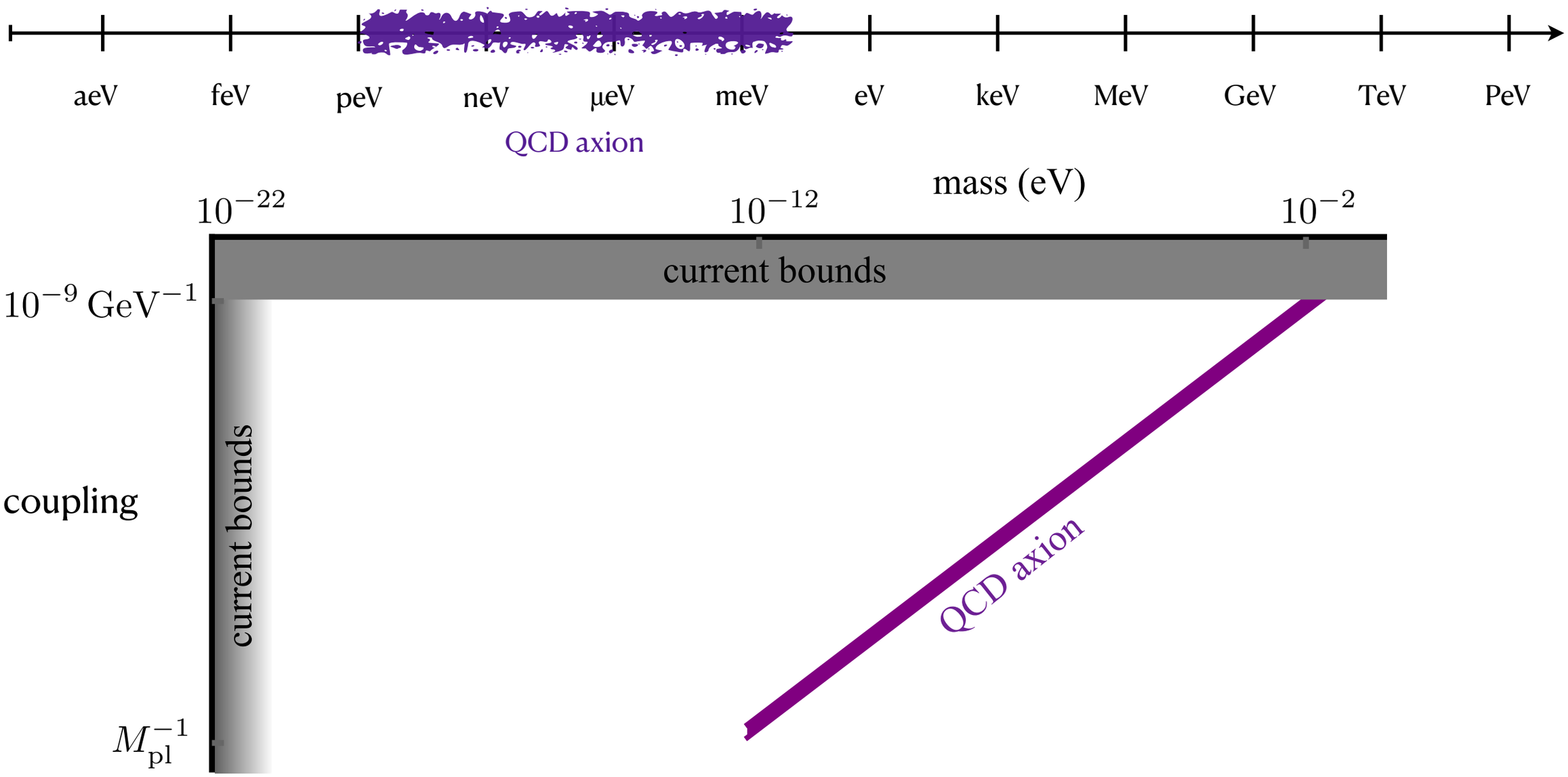
Experiments for QCD Axion DM



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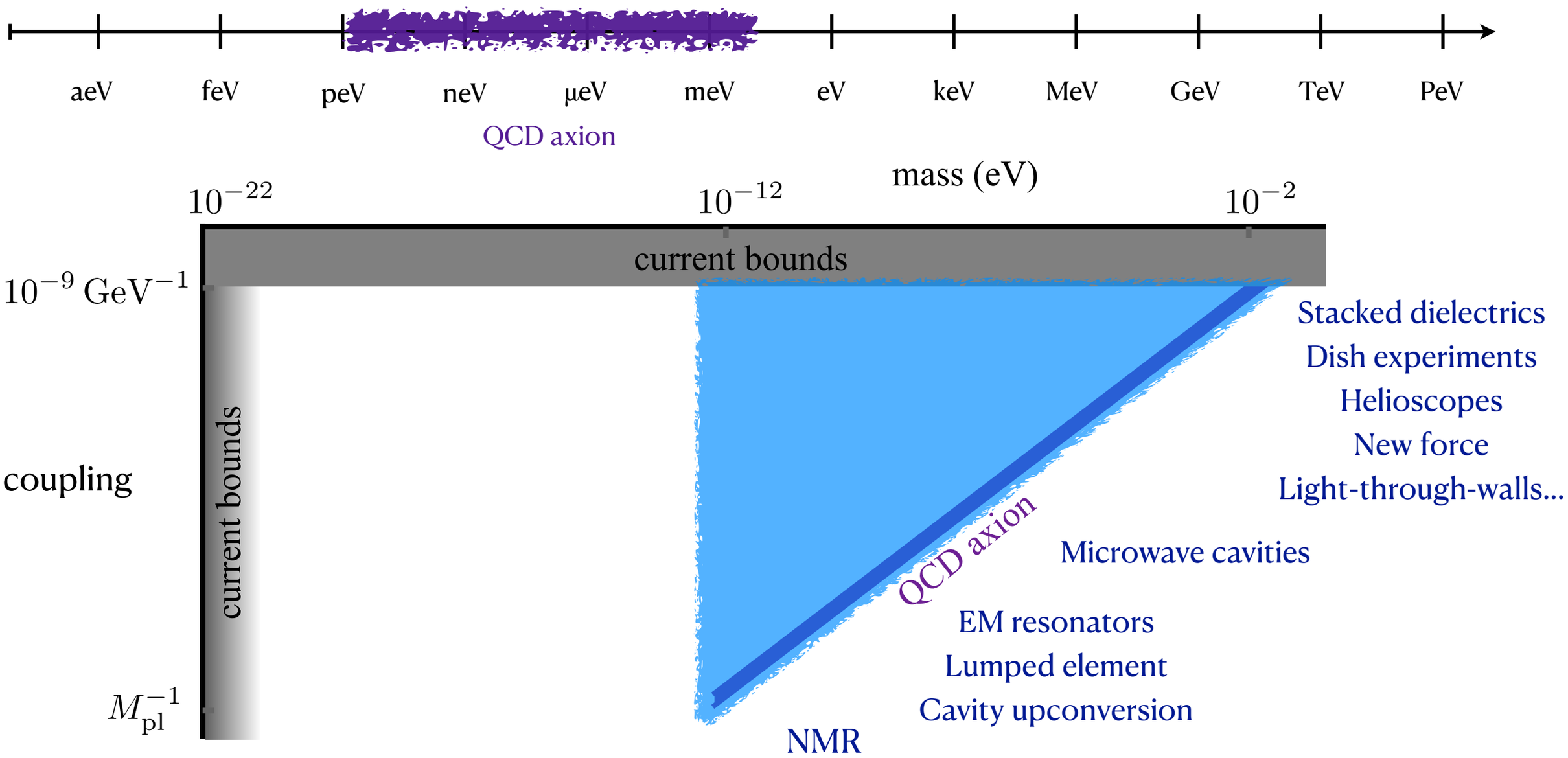

Several experiments in different frequency bands can cover entire QCD axion DM

see *Dark Matter New Initiatives* report

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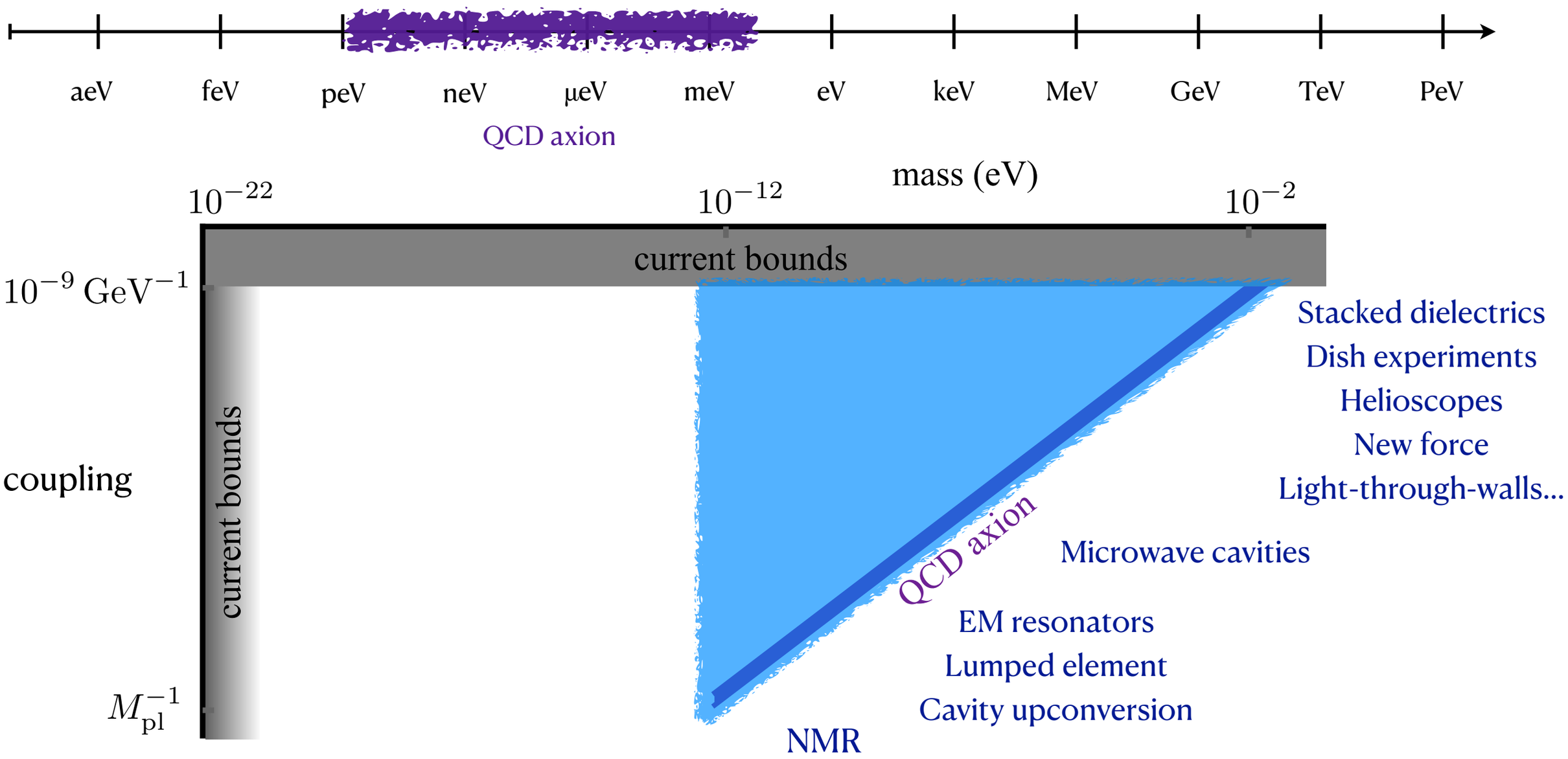

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Quantum sensing technology is key for many detectors

Demonstrates strength of theory-experiment collaborations

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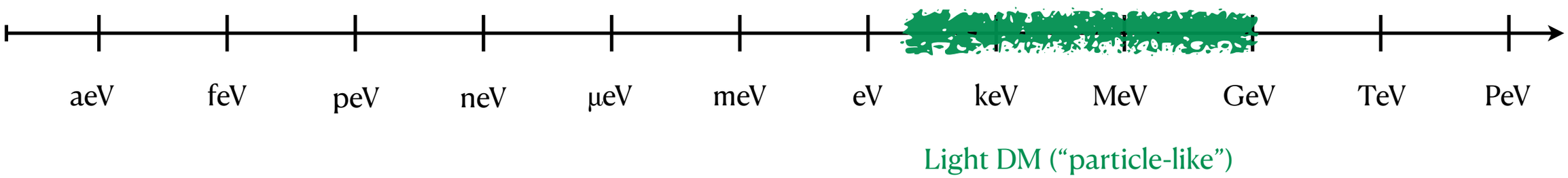
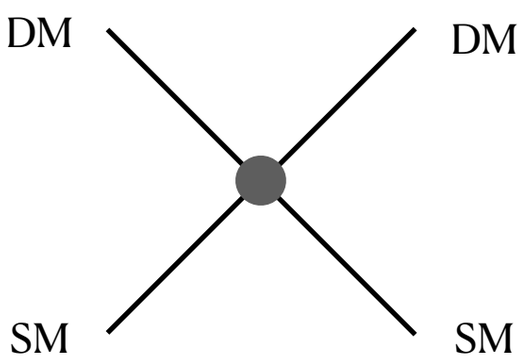
Light DM



Detecting Light DM scattering requires materials with lower thresholds than WIMP detectors



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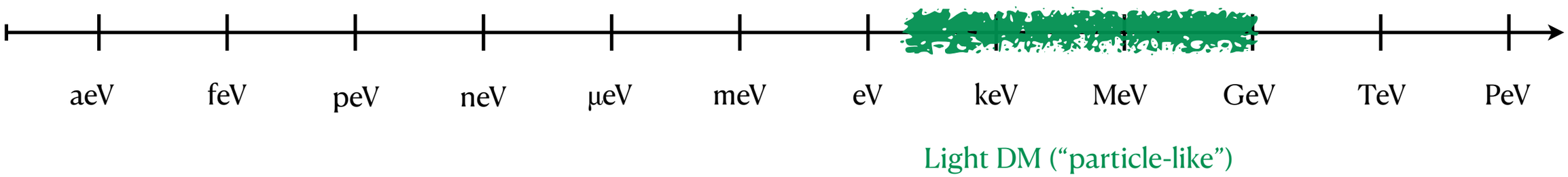

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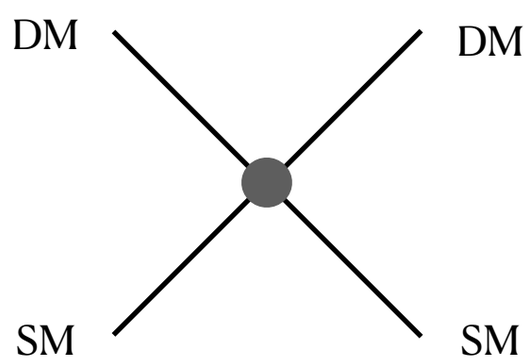
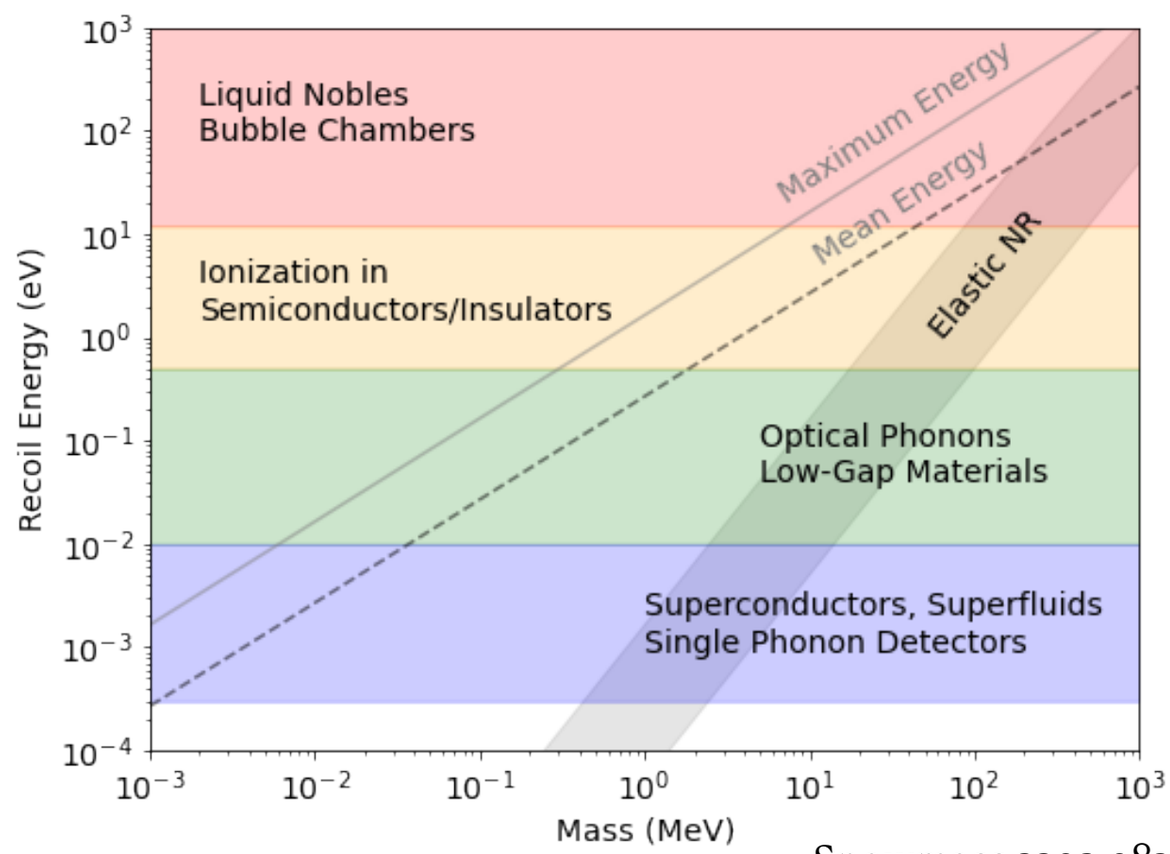


Many possible materials/experiments currently under exploration:



Snowmass 2203.08297

Exciting potential to cover large range of keV - GeV mass DM

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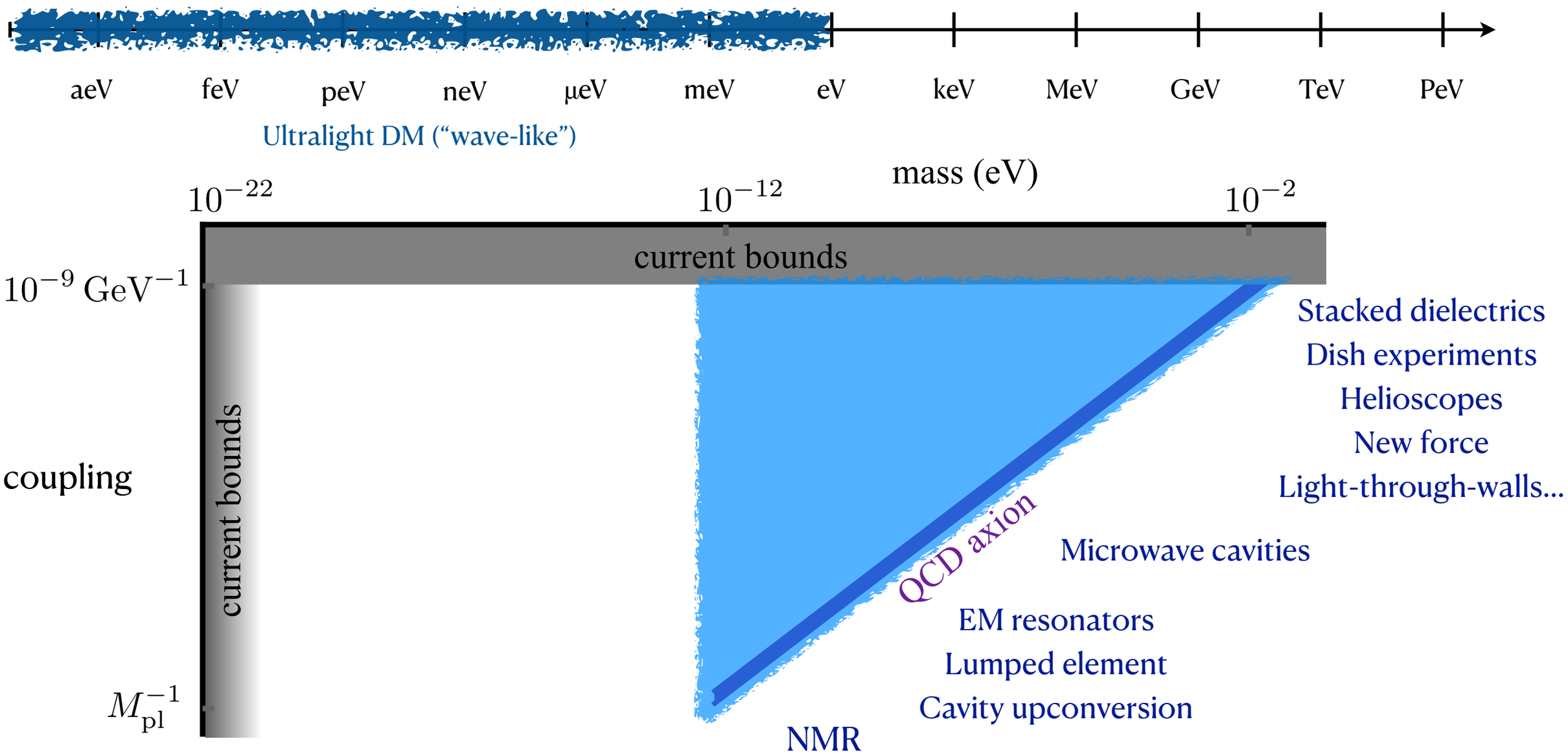
Ultralight DM



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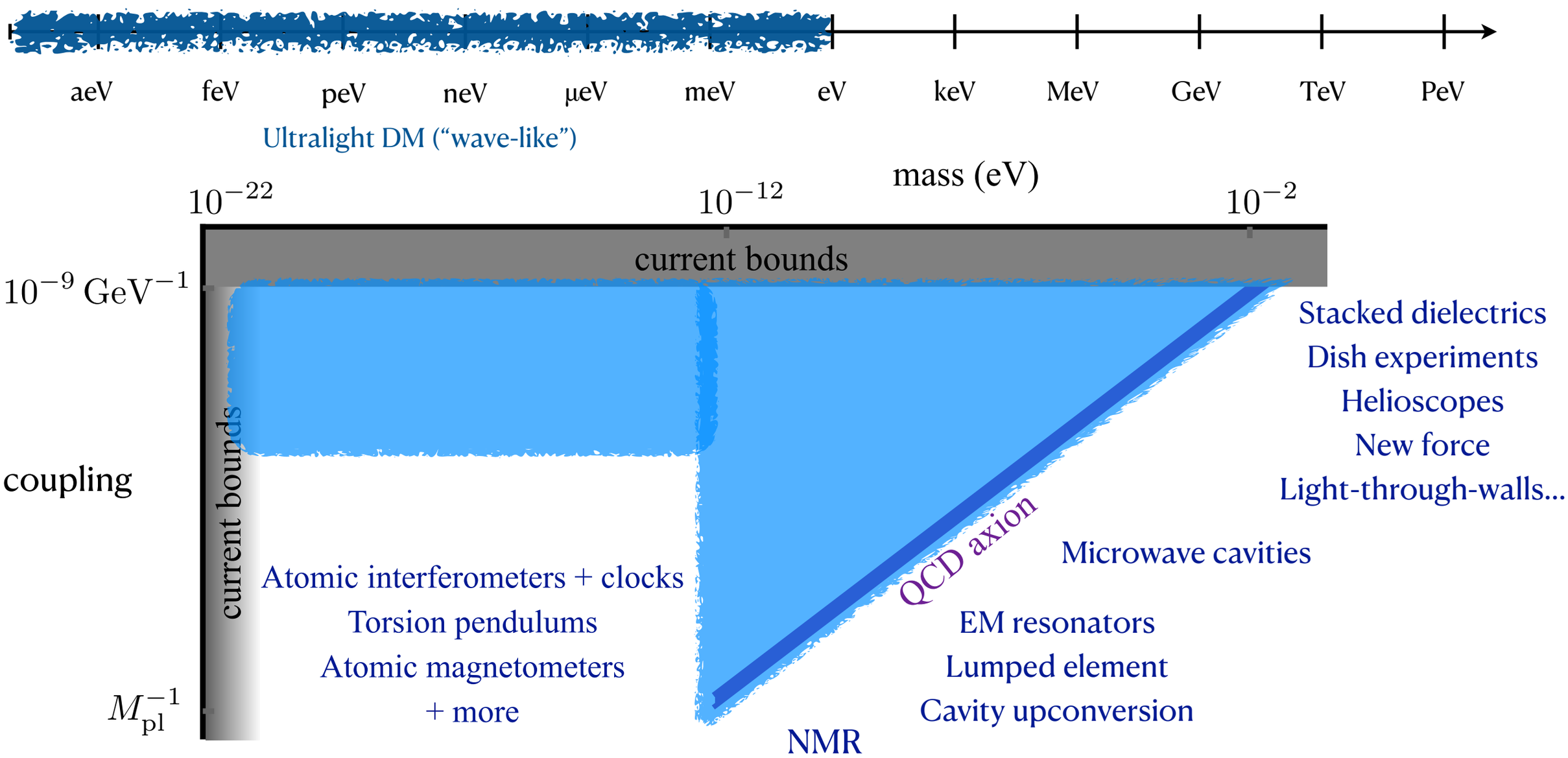

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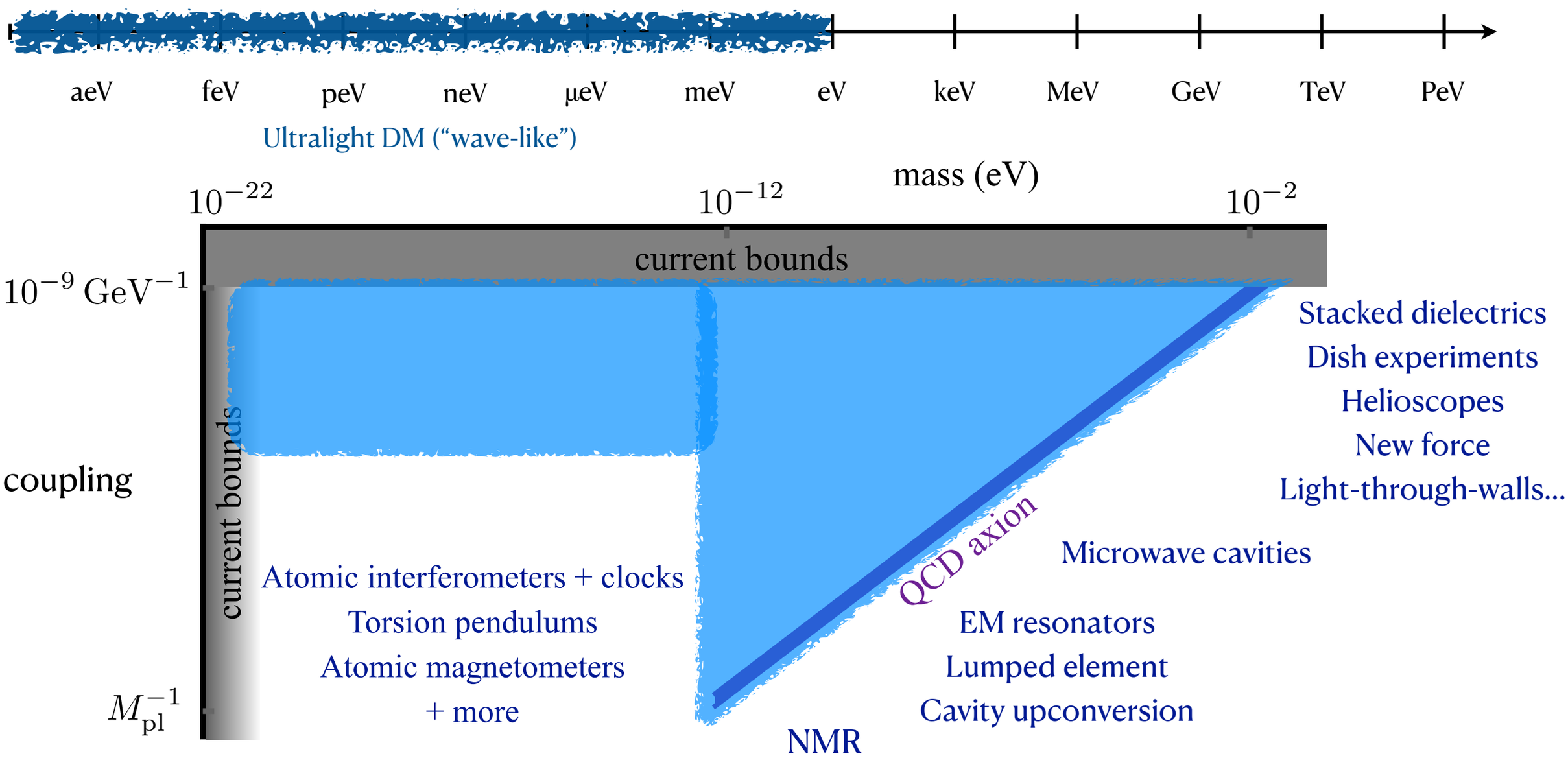

Have experiments aiming to cover the DM mass range from ~GeV to 10^{-21} eV

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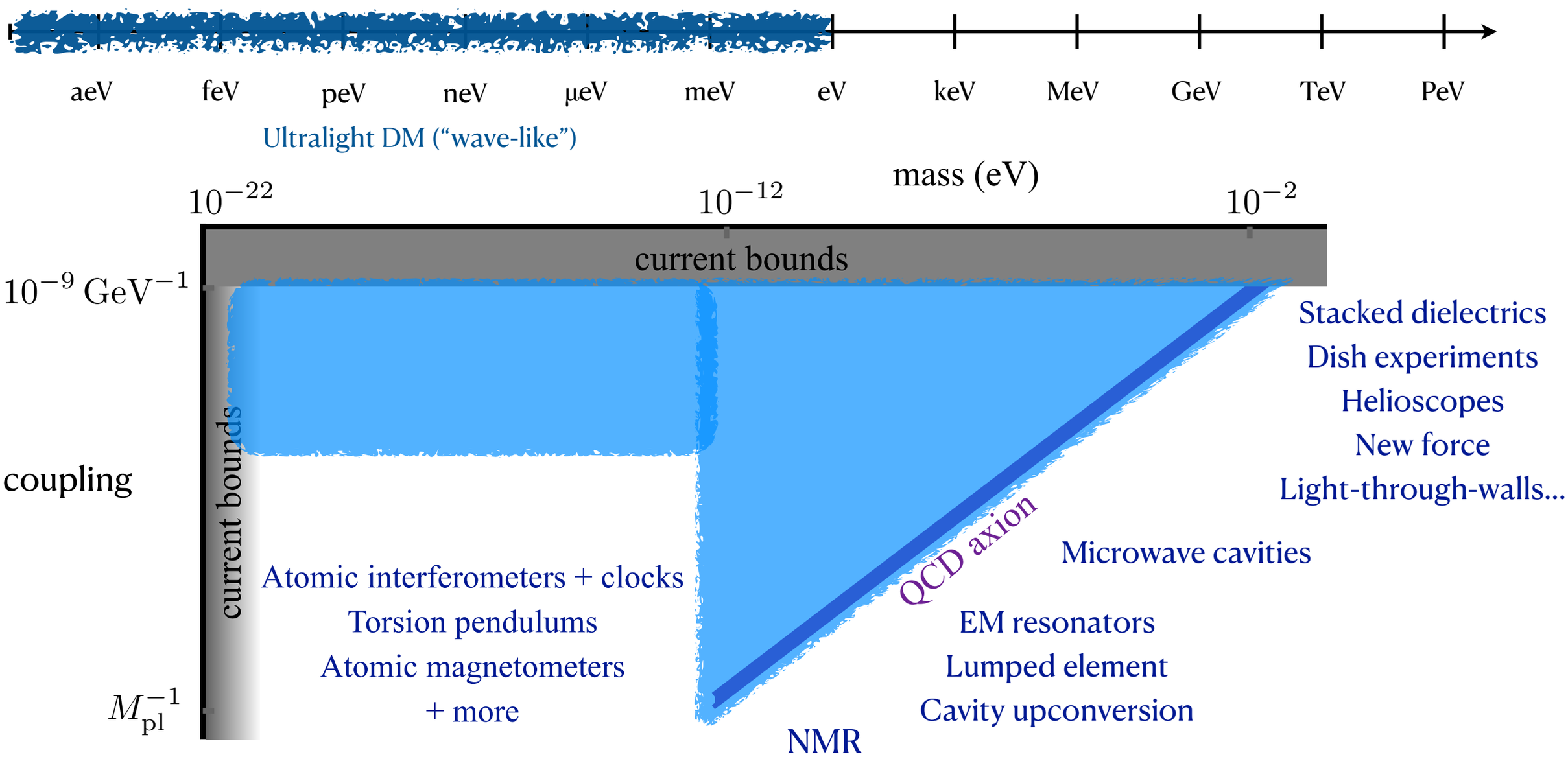

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CνB detection also very powerful probe of fundamental physics and cosmology

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5th Forces and Light Particle Production

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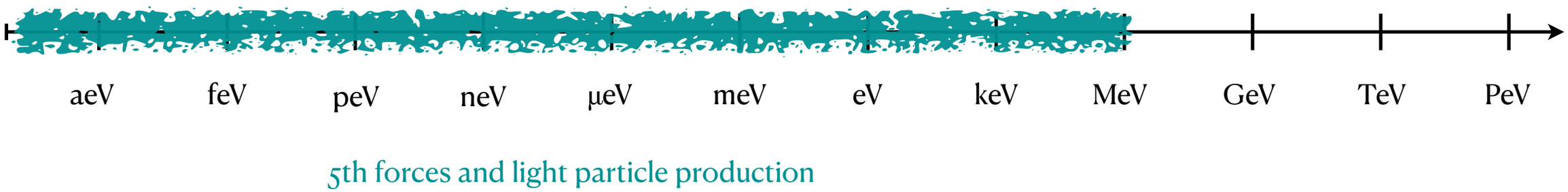
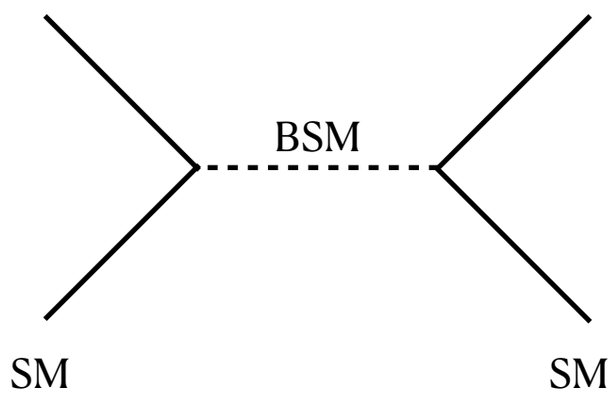
New Forces and Light Particle Production



New force mediated by light particles:



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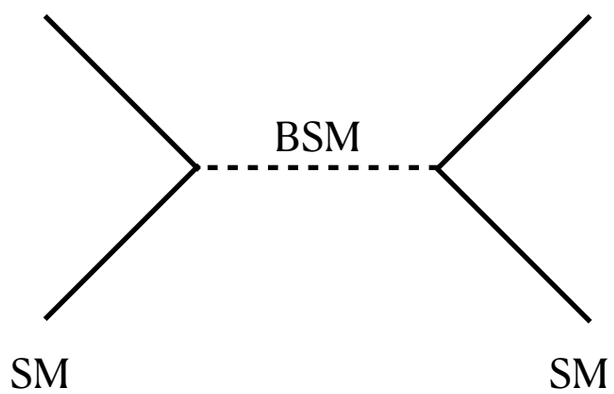


Neutron scattering

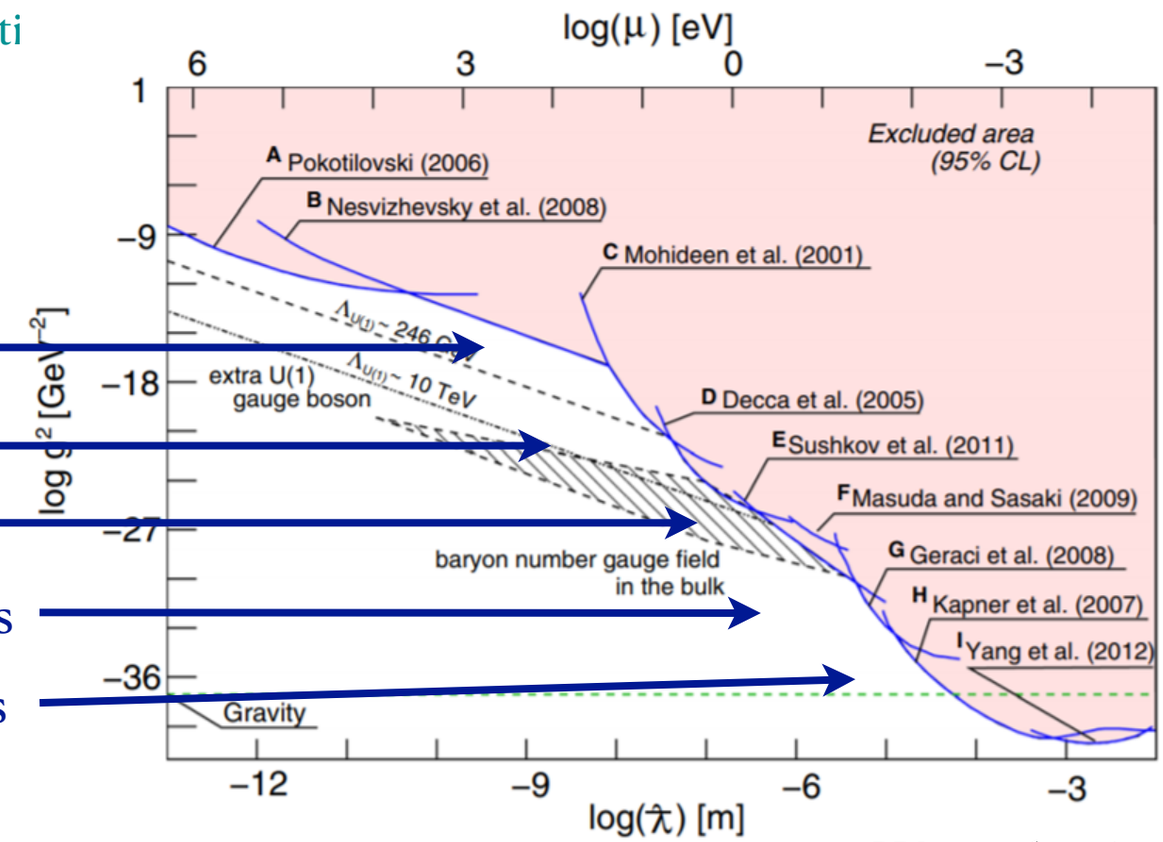
Casimir

Microcantilevers

Levitated dielectrics

Torsion pendulums

+ more...



PRL **114**, 161101 (2015)

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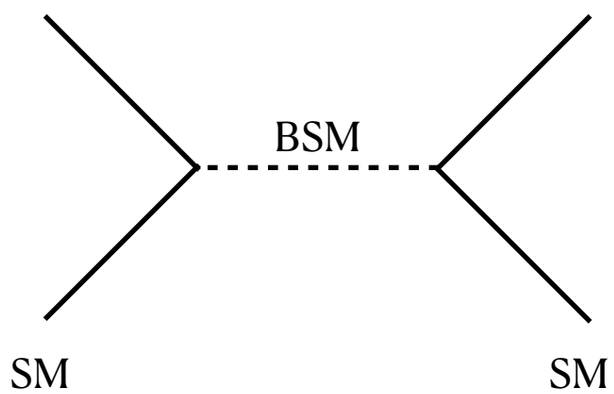
New Forces and Light Particle Production

5th forces and light particle producti

New force mediated by light particles:



Neutron scattering

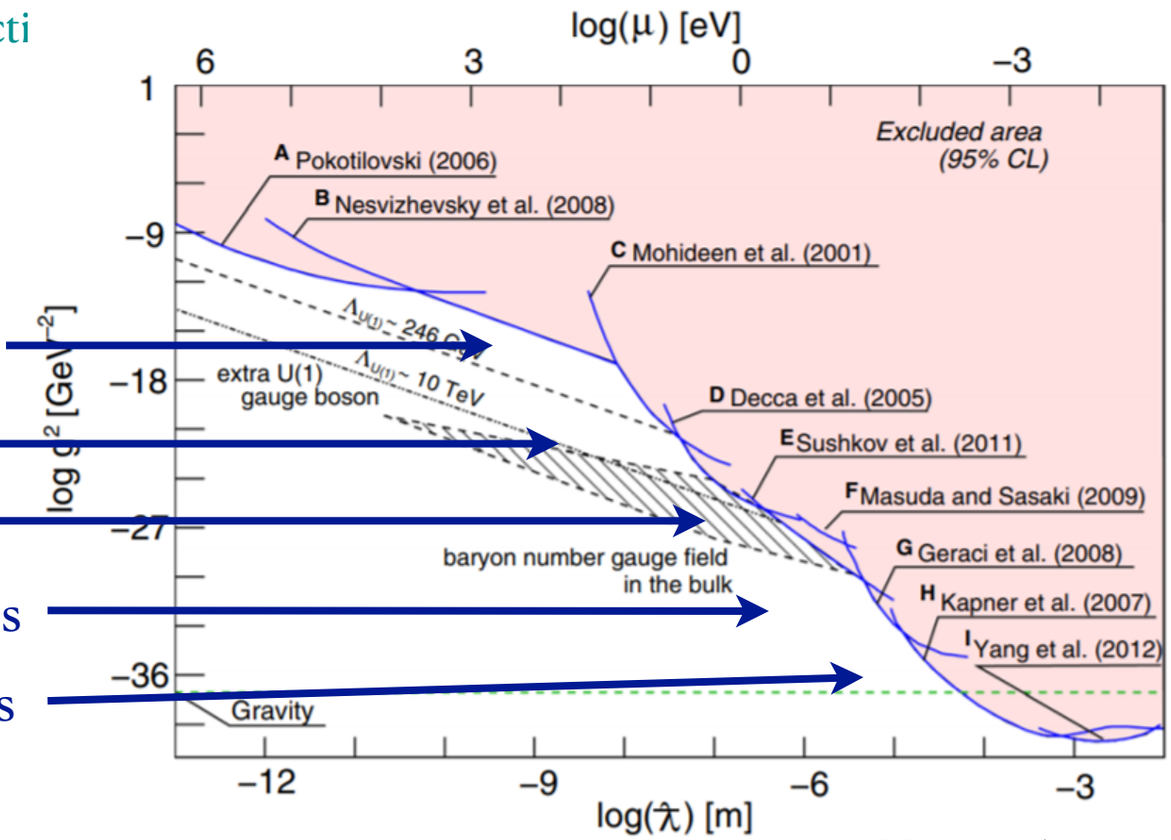
Casimir

Microcantilevers

Levitated dielectrics

Torsion pendulums

+ more...



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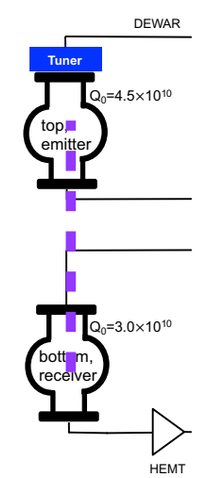
Radiate new light particles e.g.:

- light-through-walls (microwave cavity or laser) experiments for axions + dark photons
- Radioactive source experiments for ~MeV scale new particles



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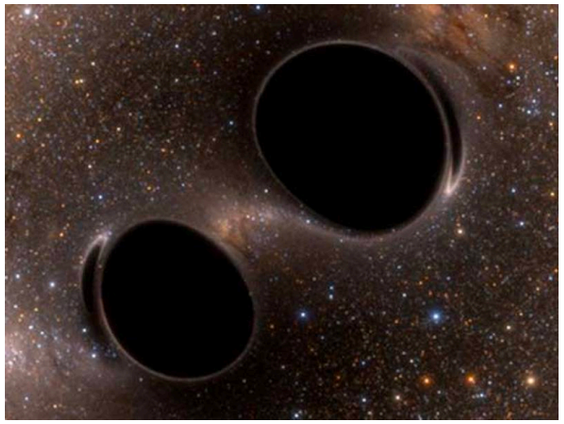
Gravitational Waves



Exciting probe of e.g. black holes, neutron stars (QCD EOS), cosmology, dark energy EOS...

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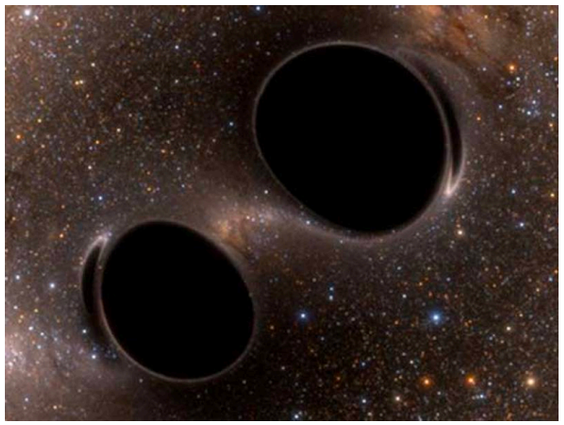

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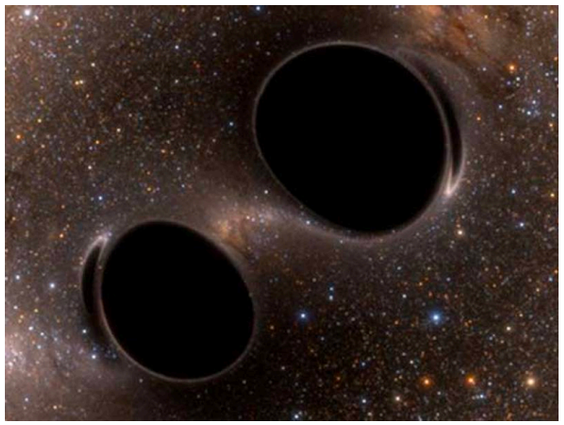

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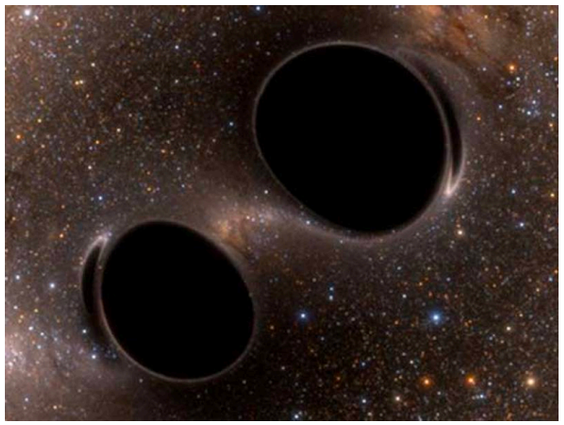

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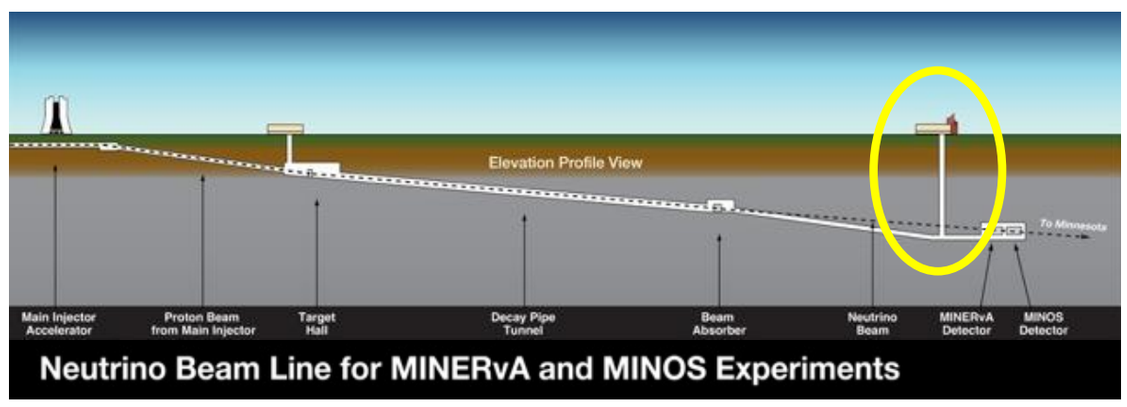
e.g. MAGIS at Fermilab atomic interferometer



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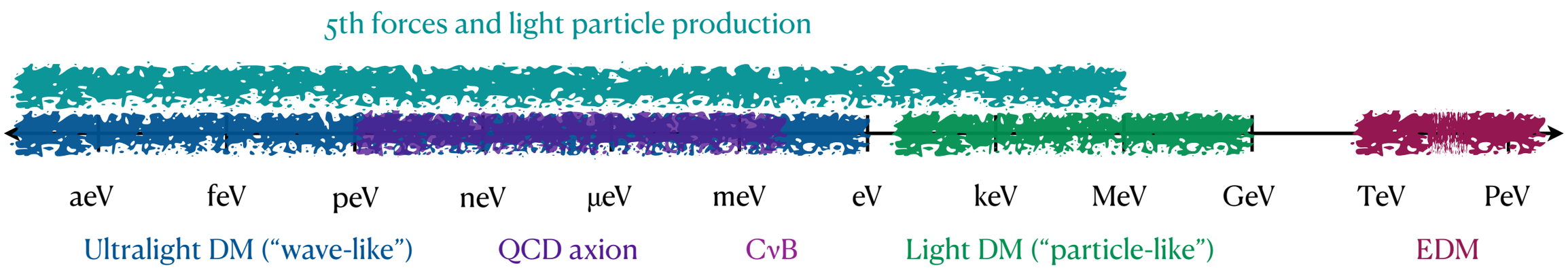
Summary



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Now a large field: many 100's of people, >40 experiments, wide range of BSM physics.

Closed caption

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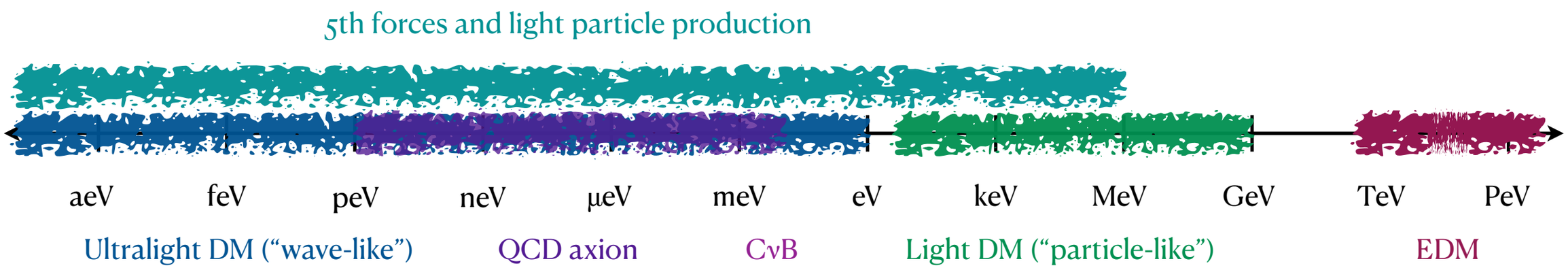

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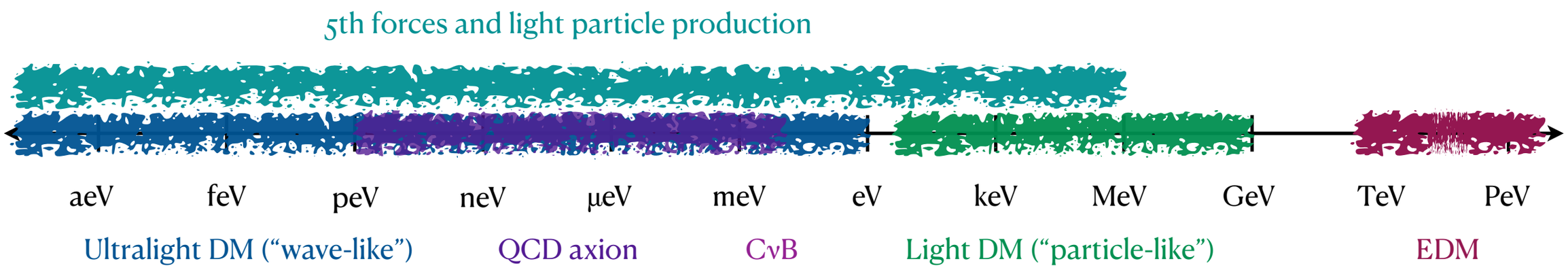

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Valuable to do R&D on many directions ~$1M initial exploration, ~$10M for full experiments

Entire suite of these experiments ~$300M total (not per year)

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