LOW ENERGY PROBES

Manifestations of the TeV scale in tabletop experiments

CONVENORS

Elina Fuchs

CERN, Hannover, PTB Braunchweig

- Isotope shift spectroscopy
- Higgs physics
- Light (pseudo-) scalars

Julian Berengut

UNSW Sydney

- Many-body theory
- Atomic and nuclear structure
- Searches for “new physics” in atomic spectra
- Novel atomic and nuclear clocks

THE ZEITGEIST

- First time for low-energy at Les Houches
- Recognises new approaches are needed for BSM
- Very connected to questions of particle physics
- Complementary to collider experiments and astronomy
- Exploits and contributes to new technologies in quantum sensing and metrology
- Big investment is being made worldwide, including at CERN

COLLIDERS VS LOW ENERGY

Colliders:
few experiments, very many experimentalists, lots of data, many theorists

Low energy:
many experiments, few experimentalists, clean data, few theorists

PARTICLE QUESTIONS $\leftrightarrow$ QUANTUM SENSING

Baryon Asymmetry

Dark Matter

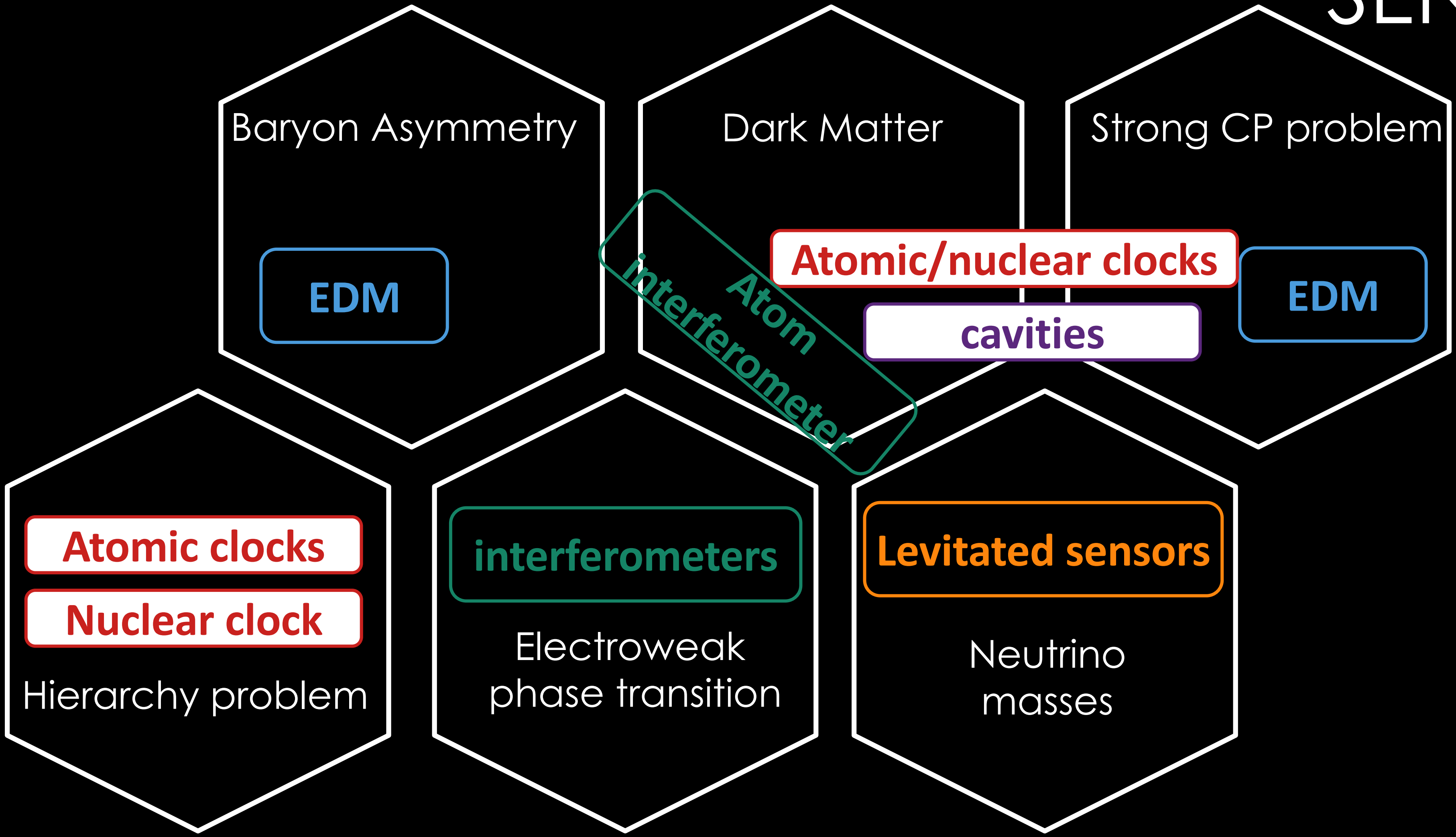
Strong CP problem

Hierarchy problem

Electroweak phase transition

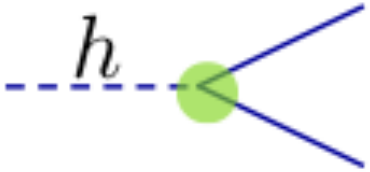
Neutrino masses

PARTICLE QUESTIONS ↔ QUANTUM SENSING

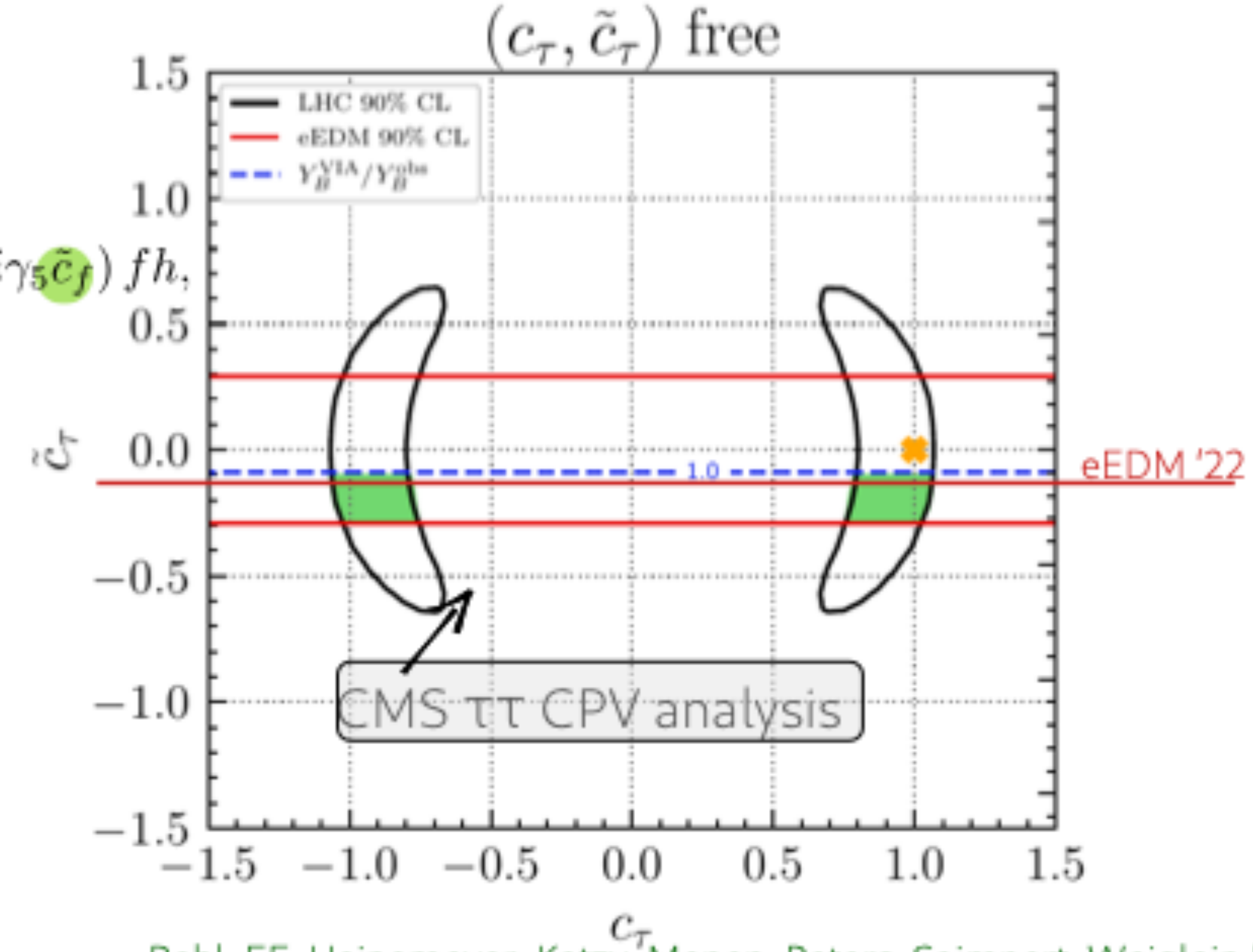


Complementary: LHC, EDM, cosmology

CP violation in Higgs sector?



$$\mathcal{L}_{\text{Yuk}} = -\sum_f \frac{y_f}{\sqrt{2}} \bar{f} \left(c_f + i\gamma_5 \tilde{c}_f \right) f h,$$



Bahl, EF, Heinemeyer, Katzy, Menen, Peters, Saimpert, Weiglein '22

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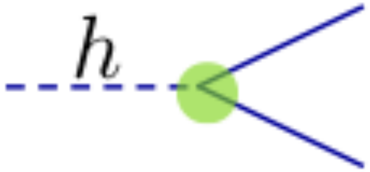

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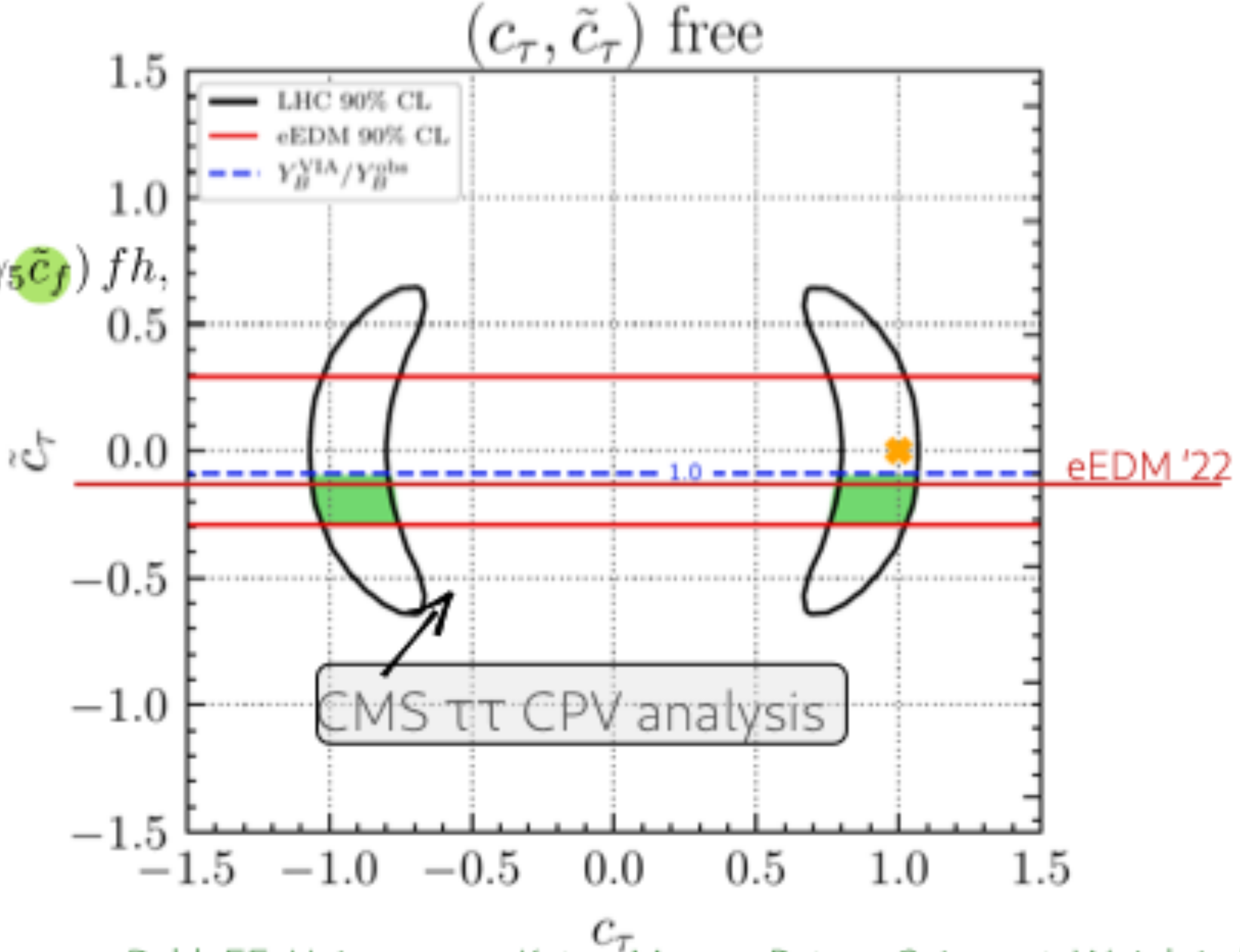
Electron electric dipole moment $d_e \propto \tilde{c}_f$



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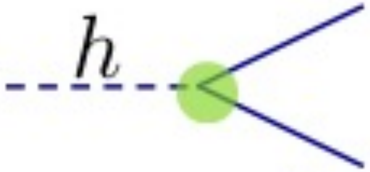

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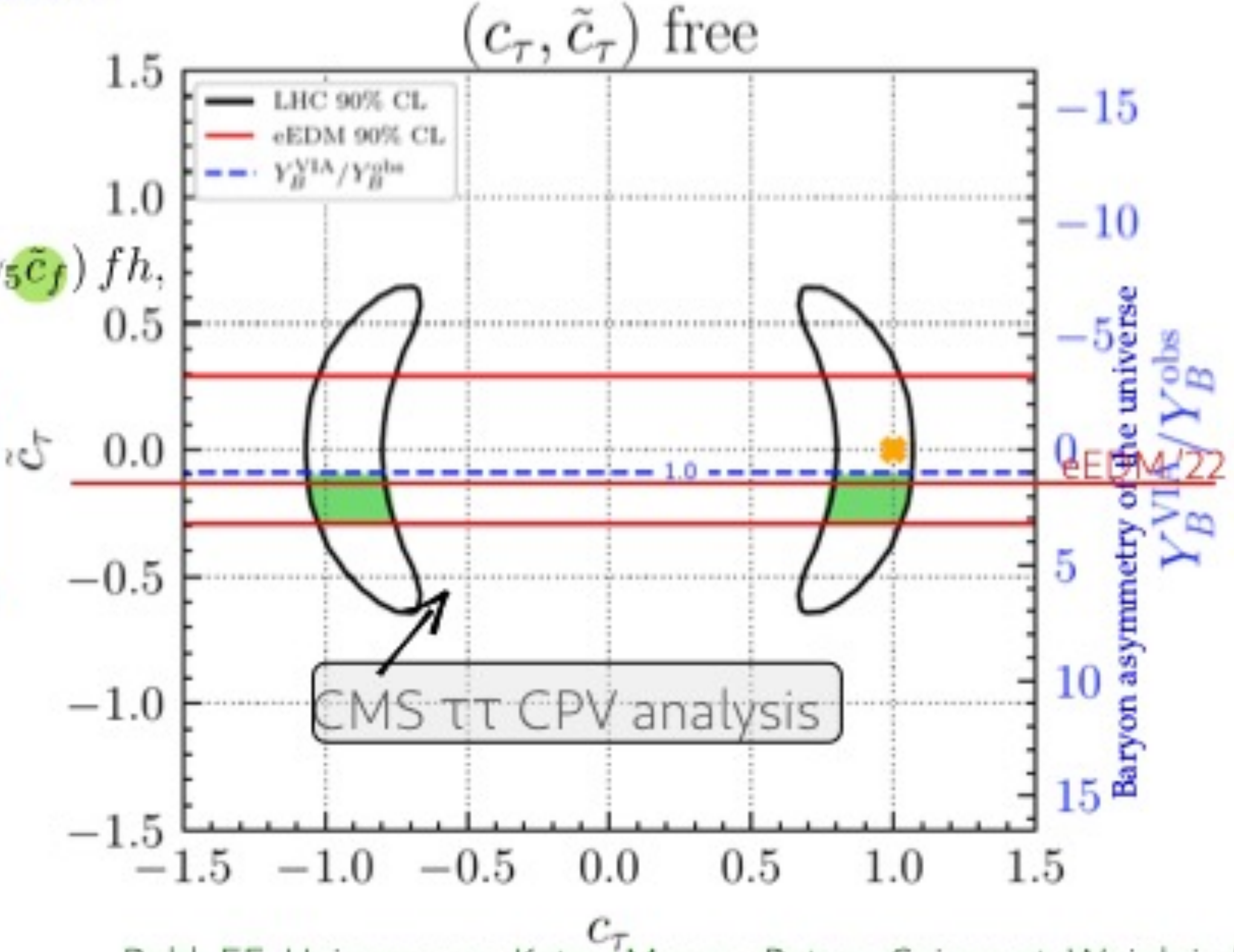

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See also

Brod, Haisch, Zupan '13

De Vries, Postma, van de Vis '18

EF, Losada, Nir, Viernik '19, '20, '20

Aharony-Shapira '21

Brod, Cornell, Skodras, Stamou '22

Electroweak baryogenesis $Y_B \propto \tilde{c}_f$

Caveat: "optimistic" scenario, large uncertainty (vev-insertion approximation) → approx. upper bound

Basler, Mühlleitner, Müller '20

Cline, Kainulainen '20

Cline, Laurent '21, Postma '21

Kainulainen '21

Postma, van de Vis, White '22

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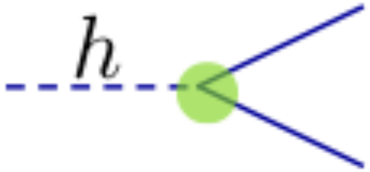

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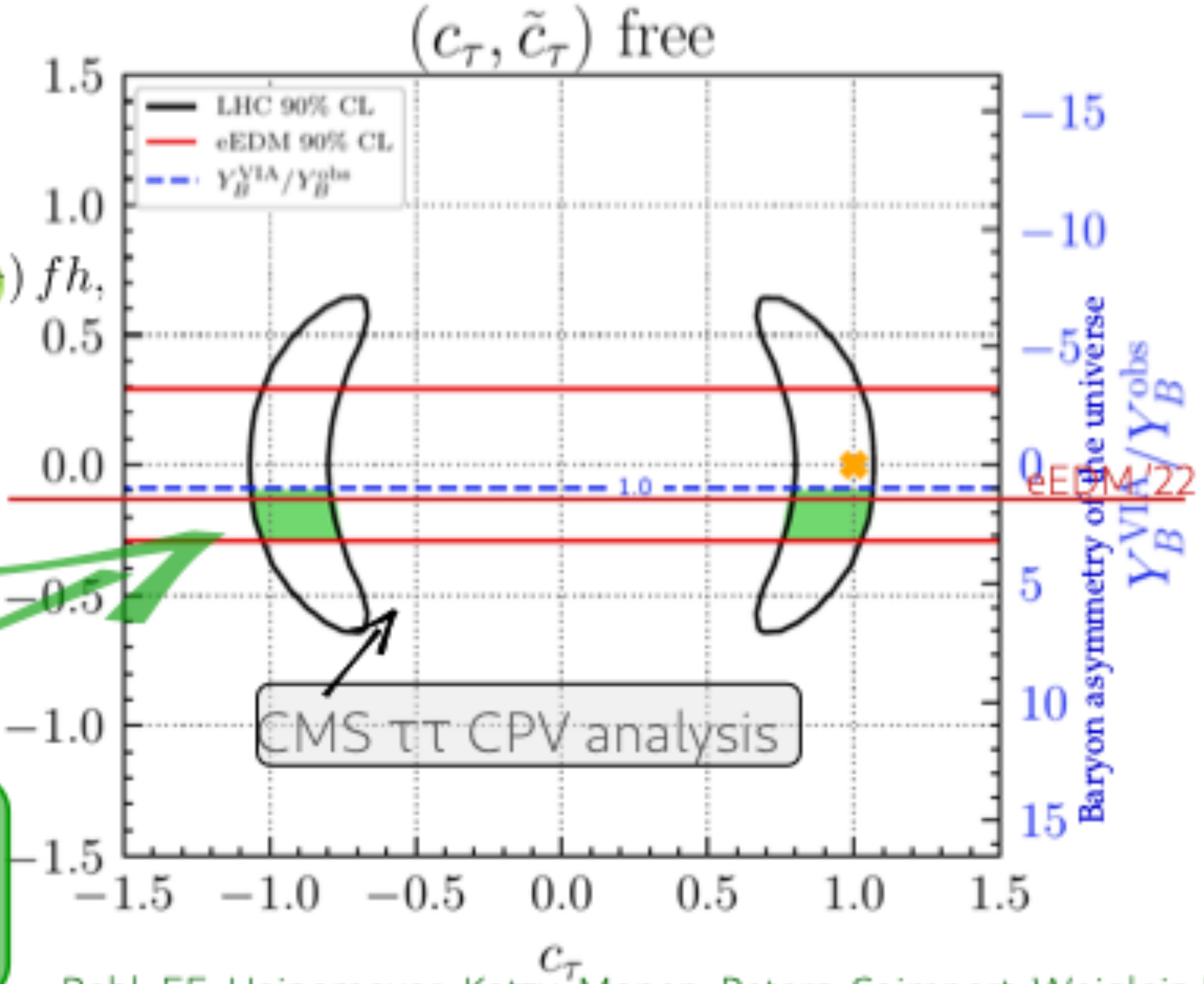

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Allowed by LHC, EDM, EWBG (if VIA correct) ⟶ τ source of CPV?

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EXPLOIT HIGH PRECISION

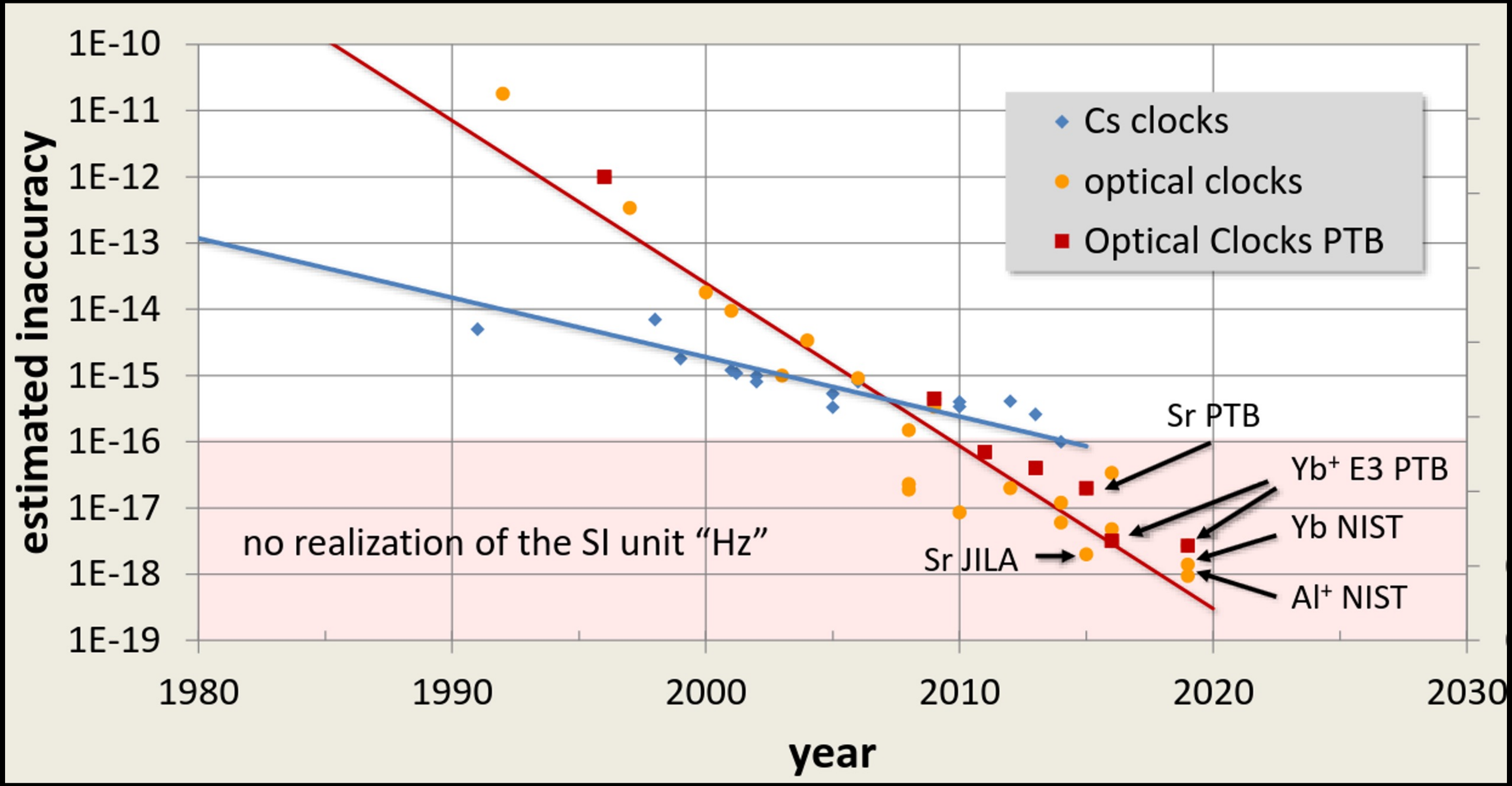
- Consider some perturbation acting on an eV-scale phenomenon

$$\Delta E \sim \frac{|V_{i0}|^2}{E_i - E_0}$$

A TeV-scale phenomenon might manifest at the 12^{th} decimal place.

- Atomic and molecular spectroscopy is very precise.

PROGRESS OF ATOMIC CLOCKS



THE MOST ACCURATELY MEASURED QUANTITY IN PHYSICS

- The most accurately measured numbers in physics are ratios of atomic clock transition frequencies:
  - ν_{Al+}/ν_{Hg+} = 1.052871833148990438 (55) [1]
    (NIST; fractional uncertainty 5.2×10^{-17})

[1]Rosenband et al. Science 319, 1808 (2008)
[2]Nemitz et al. Nat. Photonics 10, 258 (2016)
[3]*Lange et al. PRL 126 011102 (2021)*

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  - ν_{Yb}/ν_{Sr} = 1.207507039343337749 (55) [2]
    (RIKEN; fractional uncertainty 4.6×10^{-17})
  - ν_{E3}/ν_{E2} = 0.932829404530965376 (32) [3]
    (PTB; fractional uncertainty 3.4×10^{-17})
- These are sensitive to everything, but we cannot calculate the spectrum below around 1% accuracy.
- So what can we do with these?

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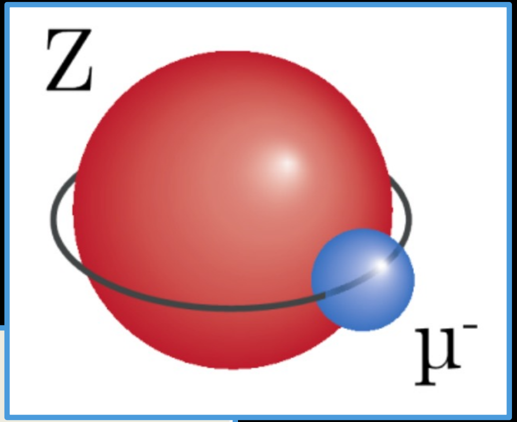
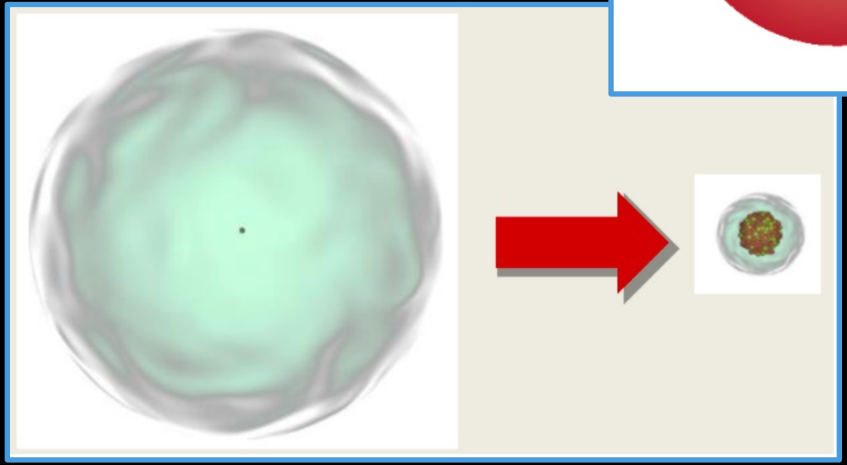
EXPLOIT HIGH PRECISION

- Differential measurements can exploit this sensitivity, e.g.
  - Parity and CP violation, neutron and electron EDMs
  - Searches for violation of local Lorentz invariance (LLI)
  - Variations of fundamental constants (α, μ)
  - Axions and axion-like particles
  - Searches for fifth forces and new force carriers
  - Hadronic physics can be sensitively probed via the nuclear interactions

EXPLOIT NEW TECHNOLOGIES

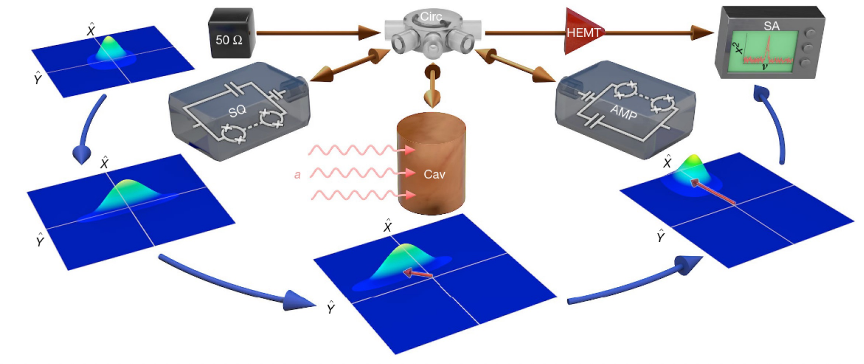
- Exotic systems for exotic physics
  - Muonic atoms
  - Highly-charged ions
  - Geonium
  - Cavities
  - Nuclear clocks
  - Rydberg states
  - Antimatter spectroscopy

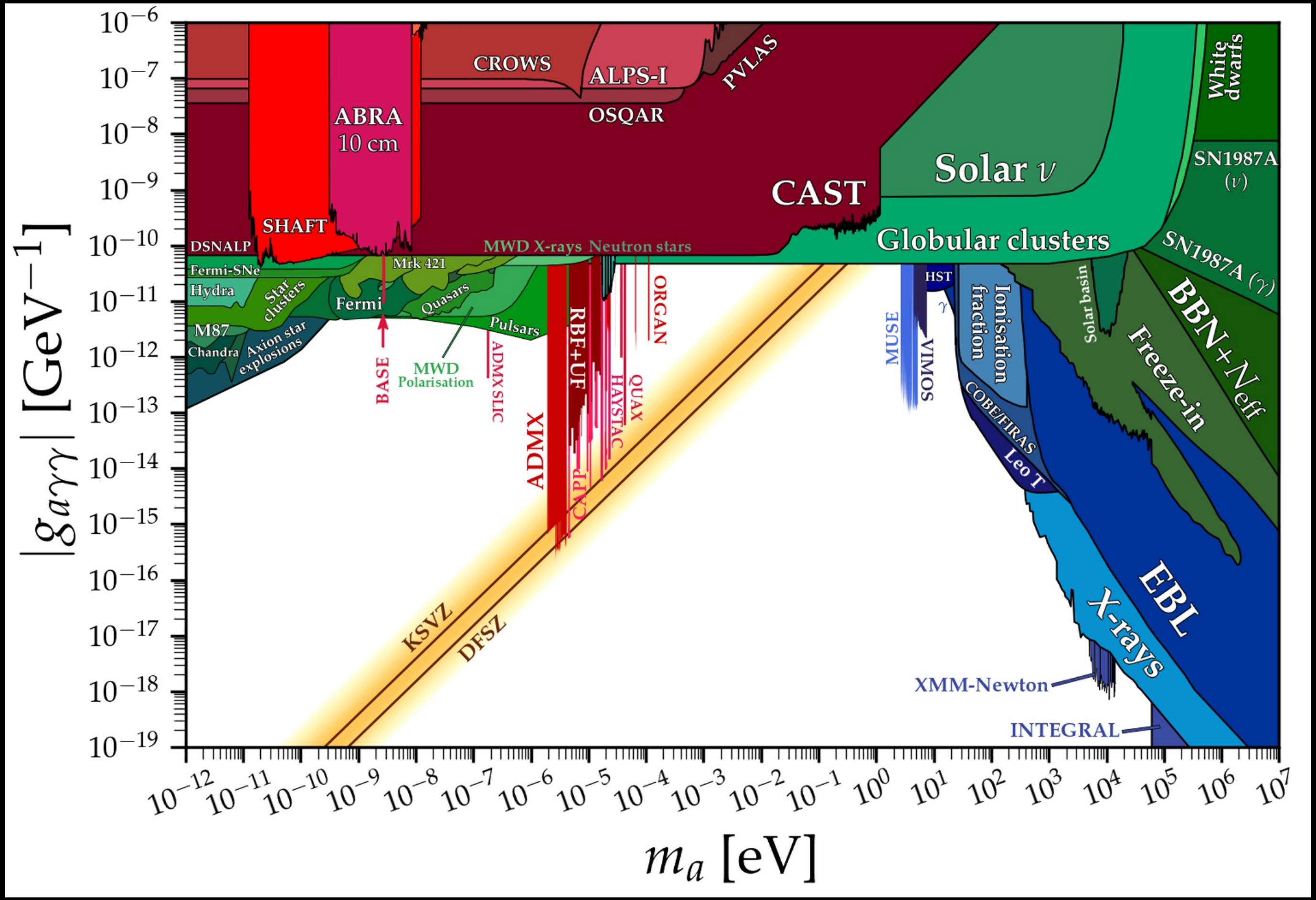




AXION-PHOTON COUPLING

Haystack already uses quantum squeezing to go beyond the Heisenberg uncertainty limit



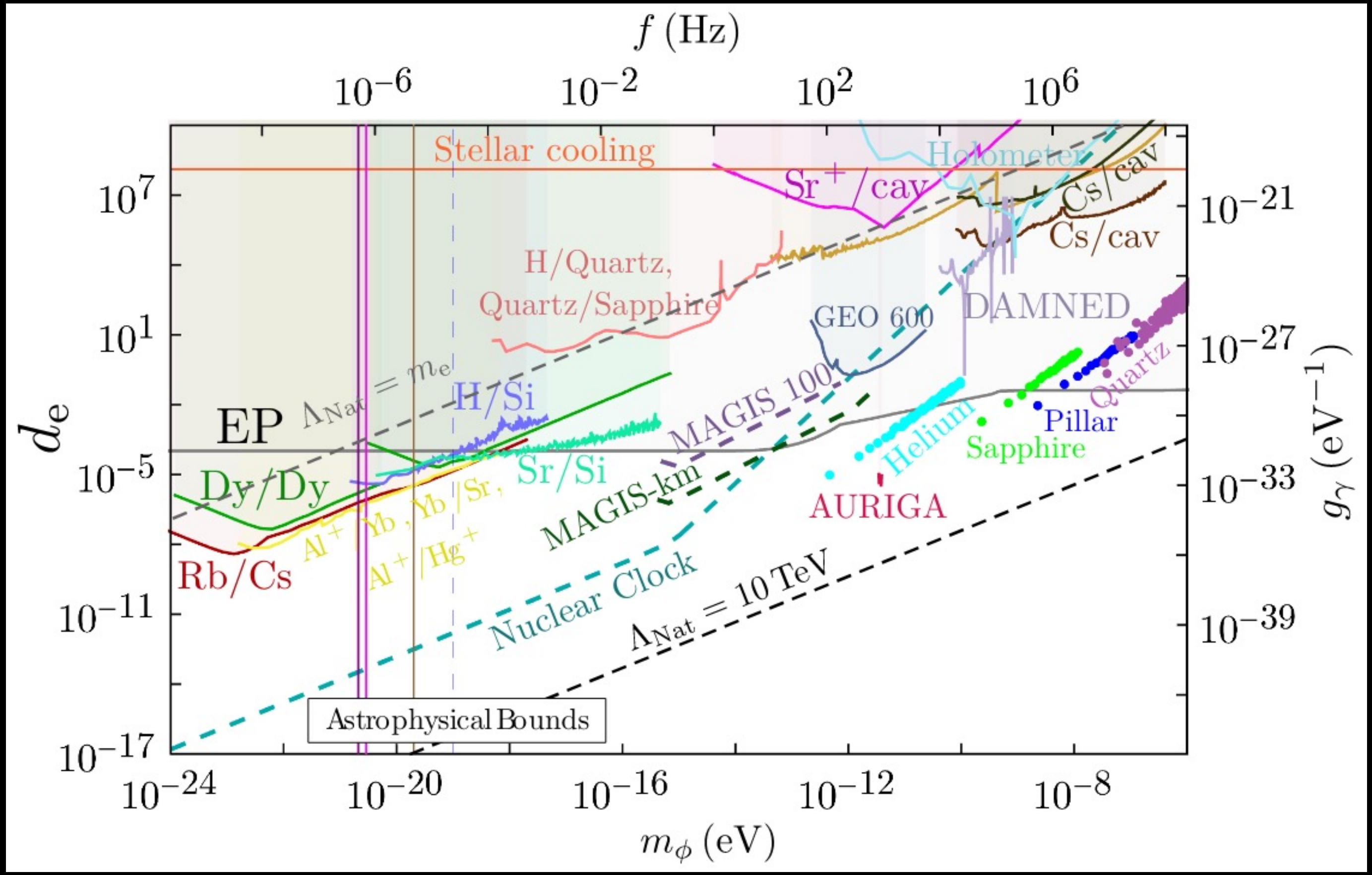


LIGHT SCALAR DARK MATTER

From Snowmass white paper

Coupling

$$L_\phi = \kappa \frac{d_e}{4} \phi \, F_{\mu\upsilon} F^{\mu\upsilon}$$



BIG OPPORTUNITY AT LES HOUCHES

- We have experts here on low-energy experiments and calculations

- Example possibilities
  - Parity violation in highly charged ions
  - New EDM searches
  - Exotic systems for BSM searches: muonic atoms, nuclear clocks, Rydberg states, bound antimatter

- Bring your ideas and see how they might manifest at low energy!