Towards a Large Scale Axion Photon Regeneration Experiment

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Axion Academic Training
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- Many models beyond the Standard Model:

  New light pseudoscalar particles, very weakly coupled to ordinary matter

- Would arise if there was a global continuous symmetry in the theory that is spontaneously broken in the vacuum

  Example:

  Axion, arising from the breaking of a U(1) Peccei-Quinn symmetry introduced to explain the absence of strong CP violation

  [Peccei, Quinn (1977); S. Weinberg (1978); Wilczek (1978)]

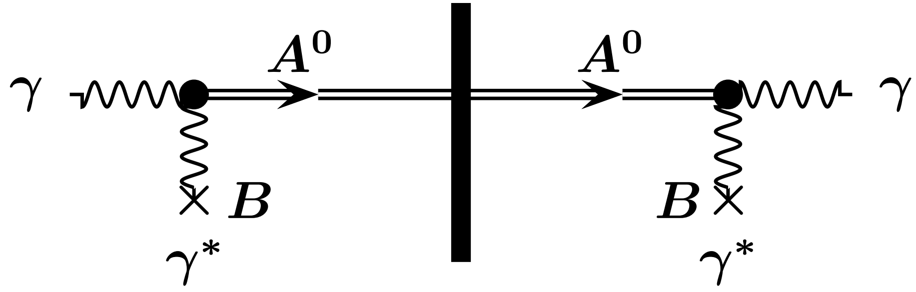
- Such pseudoscalars couple to two photons via

$$\mathcal{L}_{\phi\gamma\gamma} = -\frac{1}{4} g\,\phi\,F_{\mu\nu}\tilde{F}^{\mu\nu} = g\,\phi\,\vec{E}\cdot\vec{B},$$

⇒ In the presence of a magnetic field $\vec{B}$, a photon of frequency ω may oscillate into a pseudoscalar particle of mass $m_\phi < \omega$, and vice versa

[Sikivie (1983);Ansel'm (1985);van Bibber *et al.* (1987);Raffelt,Stodolsky (1988)]

- **Conversion probability** of photon send along magnetic field:



$$P_{\gamma\leftrightarrow\phi} \approx \frac{1}{4} g^2 B^2 \ell^2 \left(\frac{\sin\left(\frac{m_\phi^2 \ell}{4\omega}\right)}{\frac{m_\phi^2 \ell}{4\omega}} \right)^2$$

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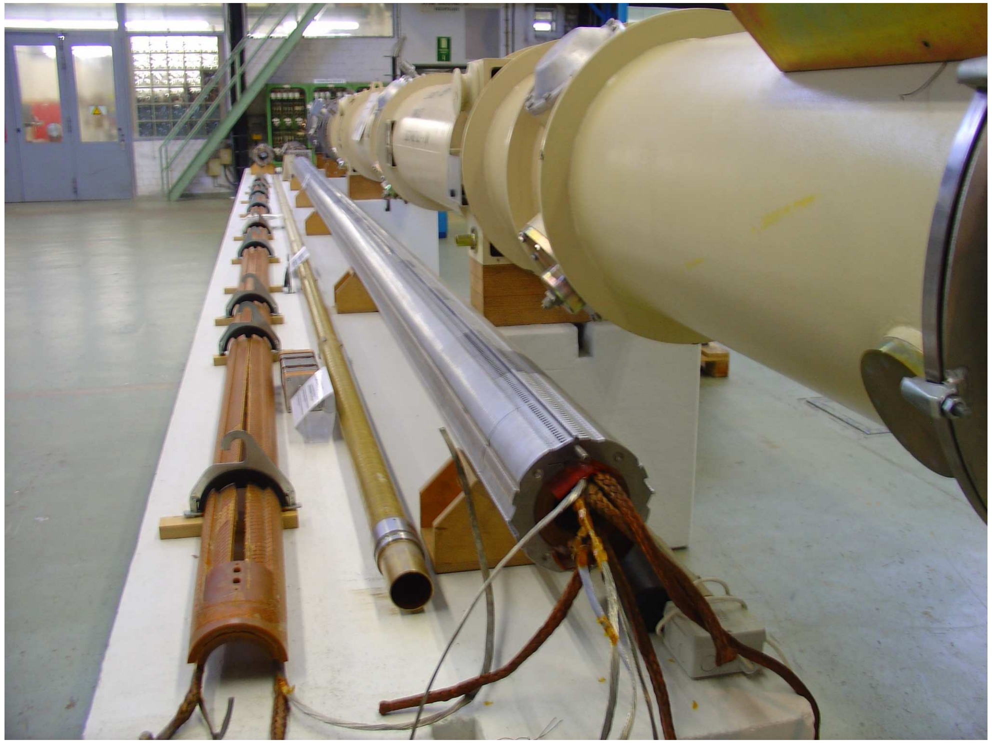
$\Rightarrow$ **Photon regeneration** optimal
  – for large $B\ell \Rightarrow$ recycle dipole magnets from accelerators

HERA dipole ($B\ell = 50$ Tm):



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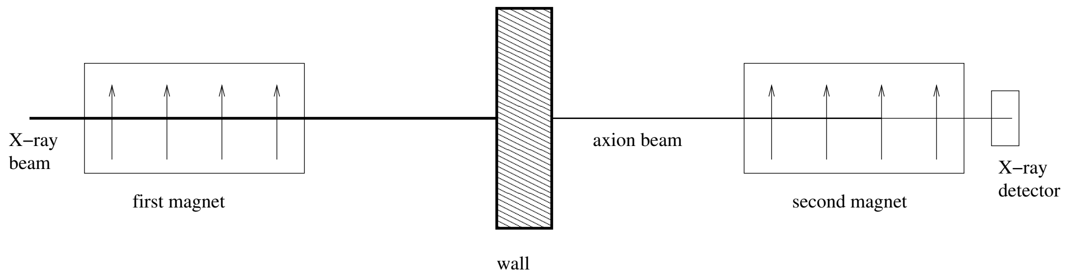
$$\text{for } \omega \gg m_\phi^2 \ell / 2\pi$$



[Rabadan,AR,Sigurdson '05]

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- for large $\boldsymbol{\omega} \Rightarrow$ exploit VUV or X-ray free-electron lasers

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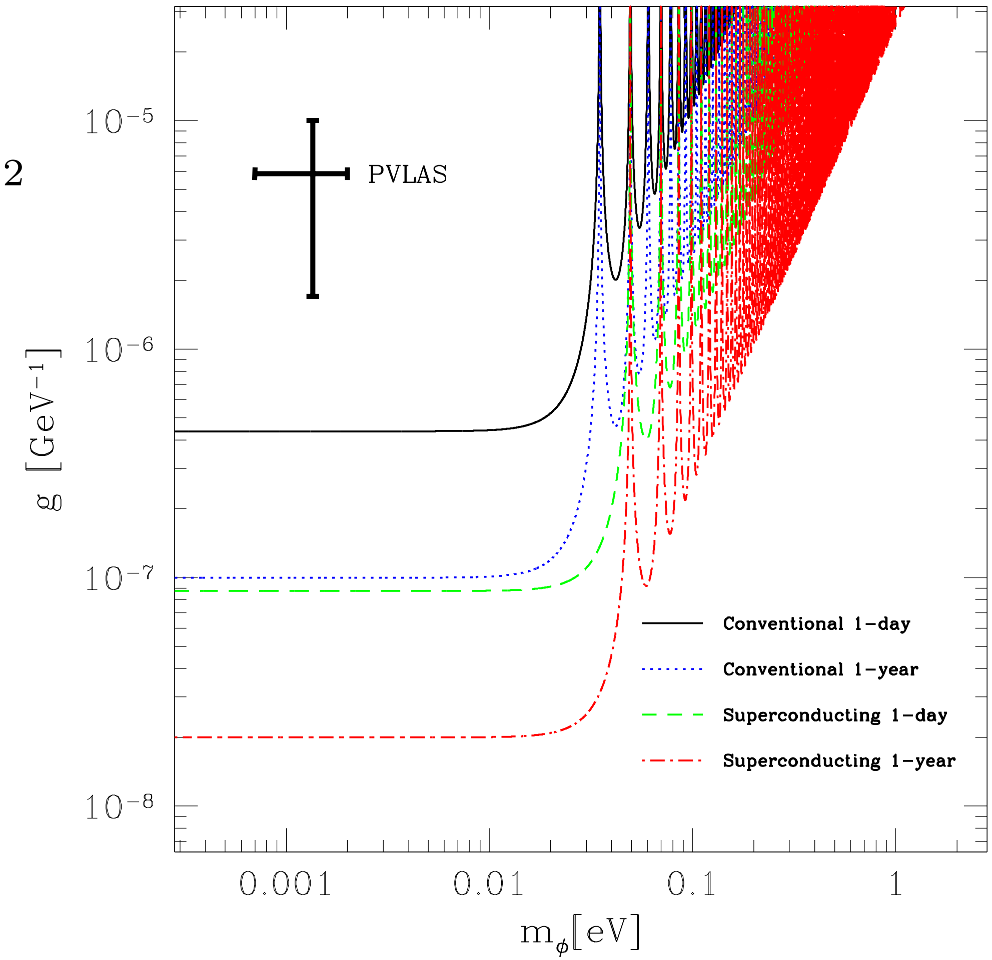


[Rabadan,AR,Sigurdson '05]

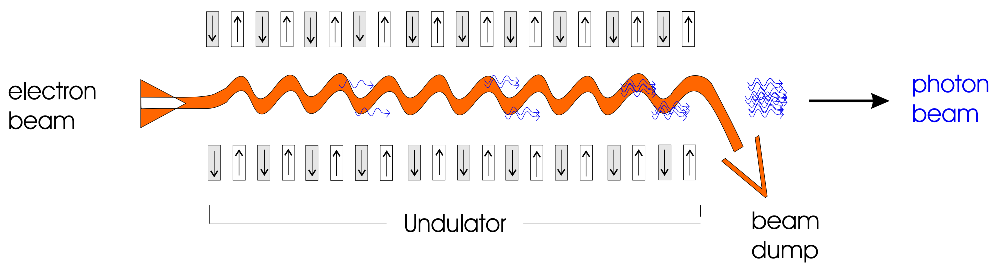
- **Powerful free-electron lasers (FEL)** already/soon available:

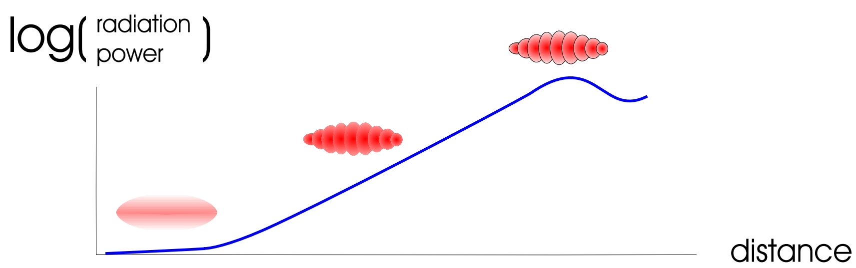
name?	ω [eV]	when?
VUV-FEL at TTF	10–200	2004
LCLS	10^4	2005–2008
XFEL	200–10^4	2005–2011

TTF: **T**ESLA **T**est **F**acility (DESY)

LCLS: **L**inac **C**oherent **L**ight **S**ource (SLAC)

SASE FEL:





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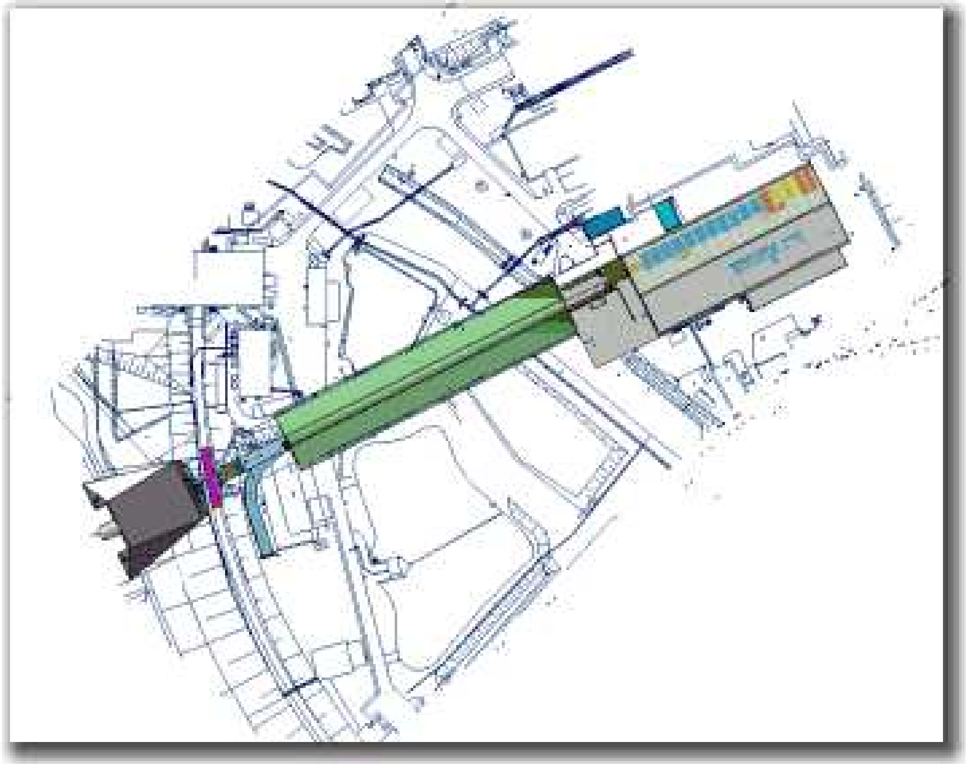
- First generation experiment may start next year

⇒ Study of feasibility underway ...

[Tschentscher,AR '05]

VUV-FEL at TTF:



Study of feasibility: [Tschentscher,AR]

- **Benchmarks:**
  - VUV-FEL:
    $\omega = 30\,\text{eV}$, $N_0 = 10^{17}\,\text{s}^{-1}$
  - HERA type magnet:
    $B = 5\,\text{T}$, $L = 2\ell = 10\,\text{m}$

$\Rightarrow$ Flux of regenerated photons:

$$N_f \approx 2 \times 10^{-3}\ \text{s}^{-1} \left(\frac{N_0}{10^{17}\ \text{s}^{-1}}\right) F^4(q\ell) \left(\frac{g}{10^{-6}\ \text{GeV}^{-1}}\right)^4 \left(\frac{B}{5\ \text{T}}\right)^4 \left(\frac{\ell}{5\ \text{m}}\right)^4$$

$\Rightarrow$ Test of PVLAS parameter region within minutes

VUV-FEL at TTF:

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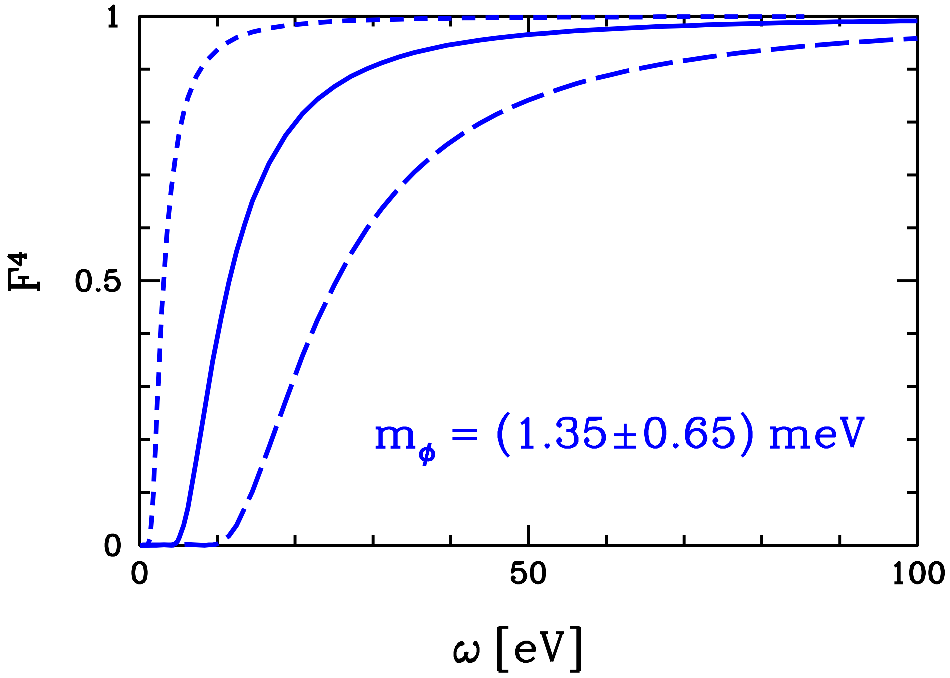


$\Rightarrow$ Test of PVLAS parameter region within minutes

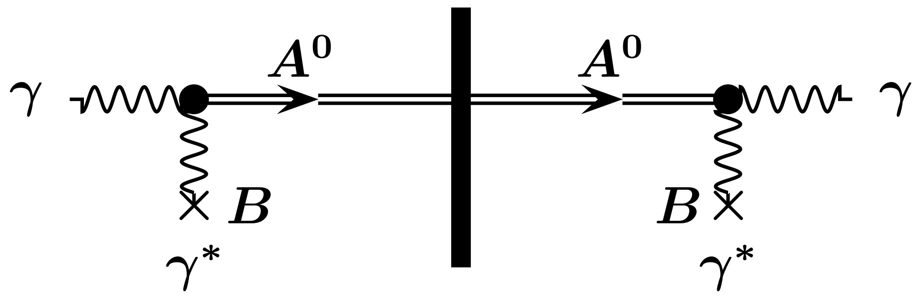
$\Rightarrow$ Determine mass by tuning ω

Study of feasibility: [Tschentscher,AR]

- Use magnet available at DESY or build new, dedicated one?

  available space (8 m × 2 m) in experimental hall too small for HERA dipole (10 m)

- Two photon detectors, one at entrance ($\rightarrow N_0$) and one at exit ($\rightarrow N_f$). Latter should have very high efficiency and low background for $\omega > 10\,$eV



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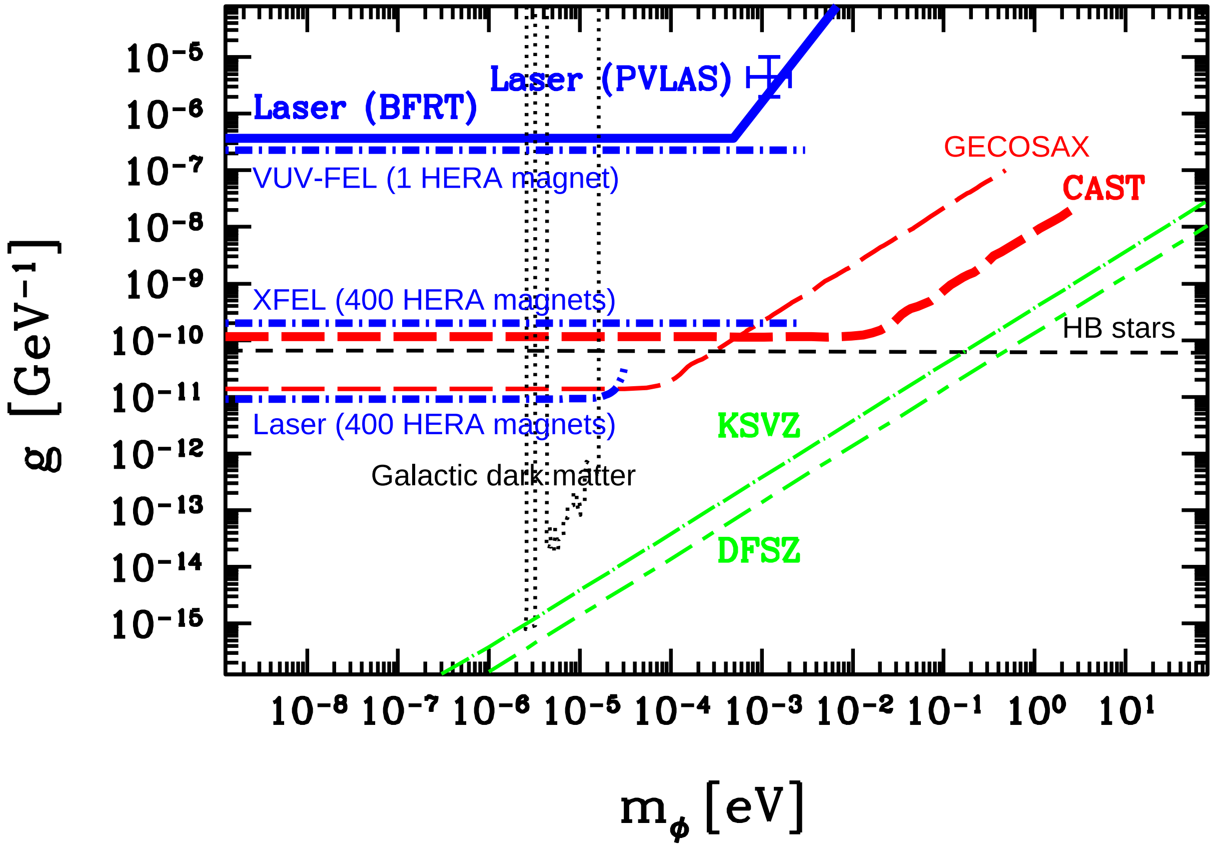
- March 2006: Proposal should be send to HASYLAB at DESY

- End of 2006: Run experiment for 12×12 h

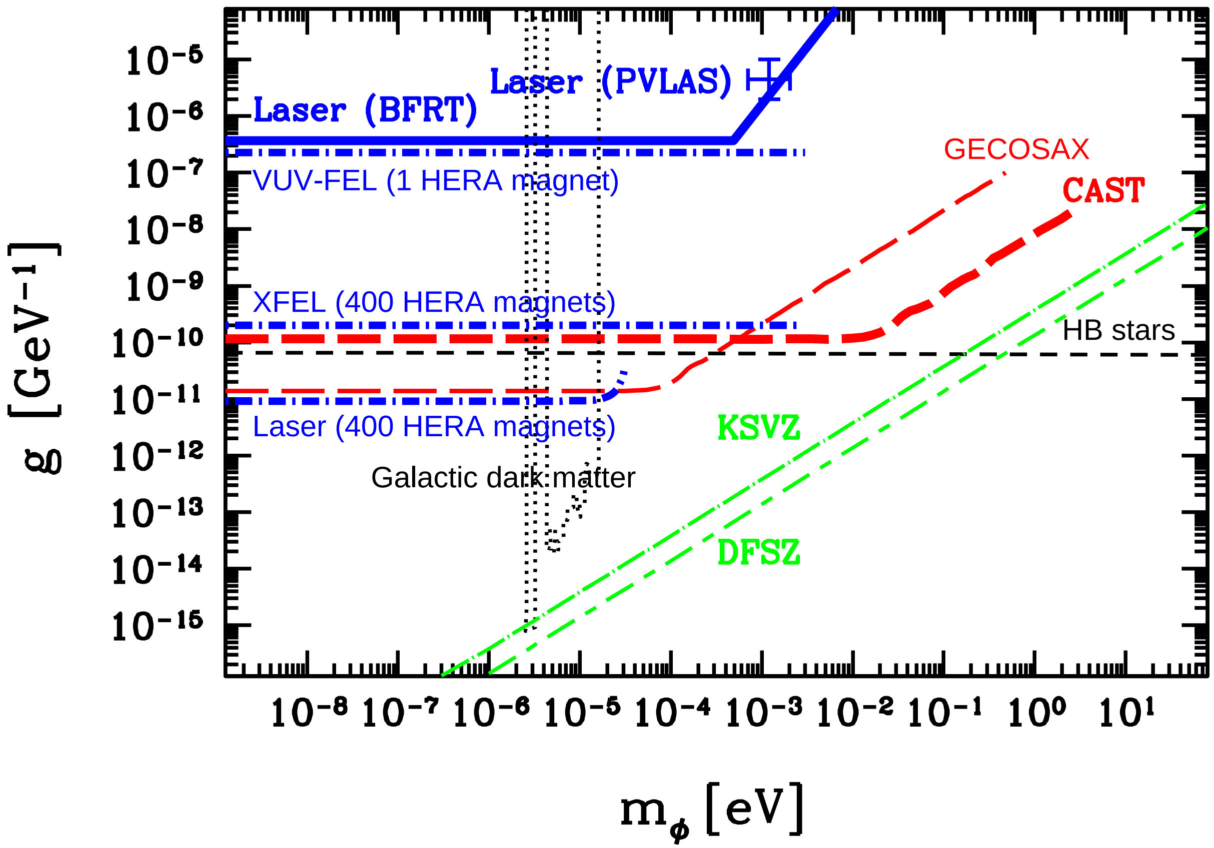


A large scale experiment: [AR '03]

- Mid 2007: decommissioning of **HERA**

⇒ Photon regeneration with ≈ 400 superconducting dipole magnets ($B = 5$ T, $\ell = 2000$ m)

- – sensitivity comparable to limits involving astrophysical considerations (HB stars; su)
- – $B\ell$ still not large enough to be sensitive to the region where the axion qualifies as a cold dark matter candidate



- We need the **(V)LHC** magnets!

Conclusions

- Powerful VUV and X-ray FEL's, combined with recycled dipole magnets from accelerators, offer unique possibility for photon regeneration experiments
  - sensitivity towards larger m_ϕ as compared to optical lasers
  - detection efficiency of order unity
  - mass determination through tuning of ω
- PVLAS indication can be tested already next year with modest experiment
- Scheme can be expanded towards a large scale experiment