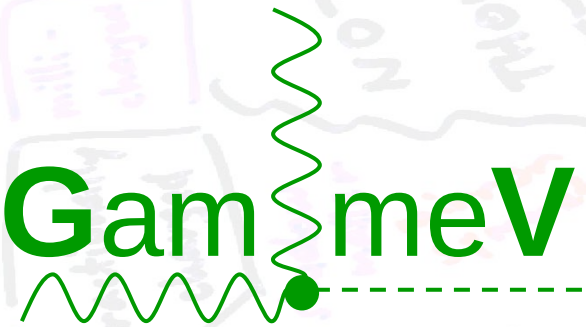


Gamma to milli-eV particle search

William Wester, Fermilab
for the **G**amme**V** Collaboration

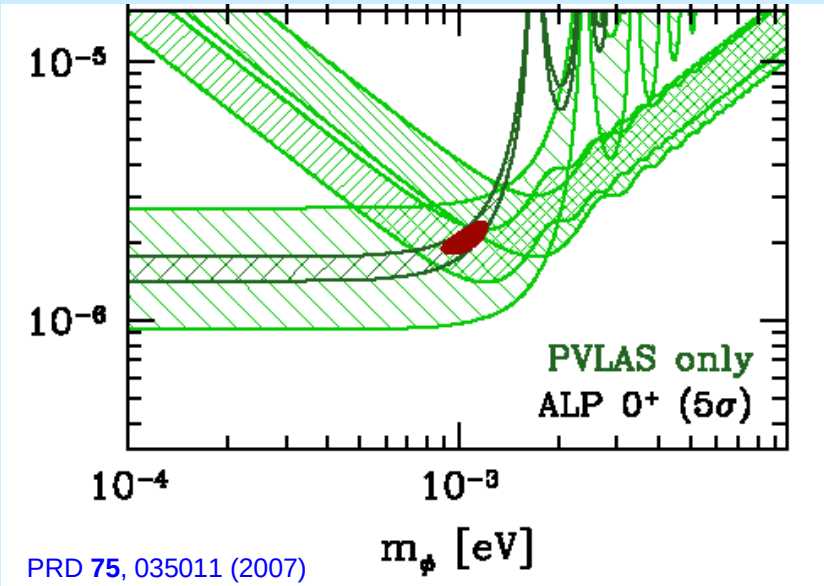
milli-eV Mass Scale

- milli-eV (10^{-3}) eV mass scale arises in various areas in modern particle physics.
  - Dark Energy density
    - $\Lambda^4 = 7 \times 10^{-30}$ g/cm^3 ~ $(2 \times 10^{-3}$ eV$)^4$
  - Neutrinos
    - $(\Delta m_{21})^2 = (9 \times 10^{-3}$ eV$)^2$
    - $(\Delta m_{32})^2 = (50 \times 10^{-3}$ eV$)^2$
  - See-saw with the TeV scale:
    - meV ~ TeV$^2/M_{planck}$ String theory
  - Dark Matter Candidates
    - Certain SUSY sparticles (low mass gravitino)
    - Axions and axion-like particles

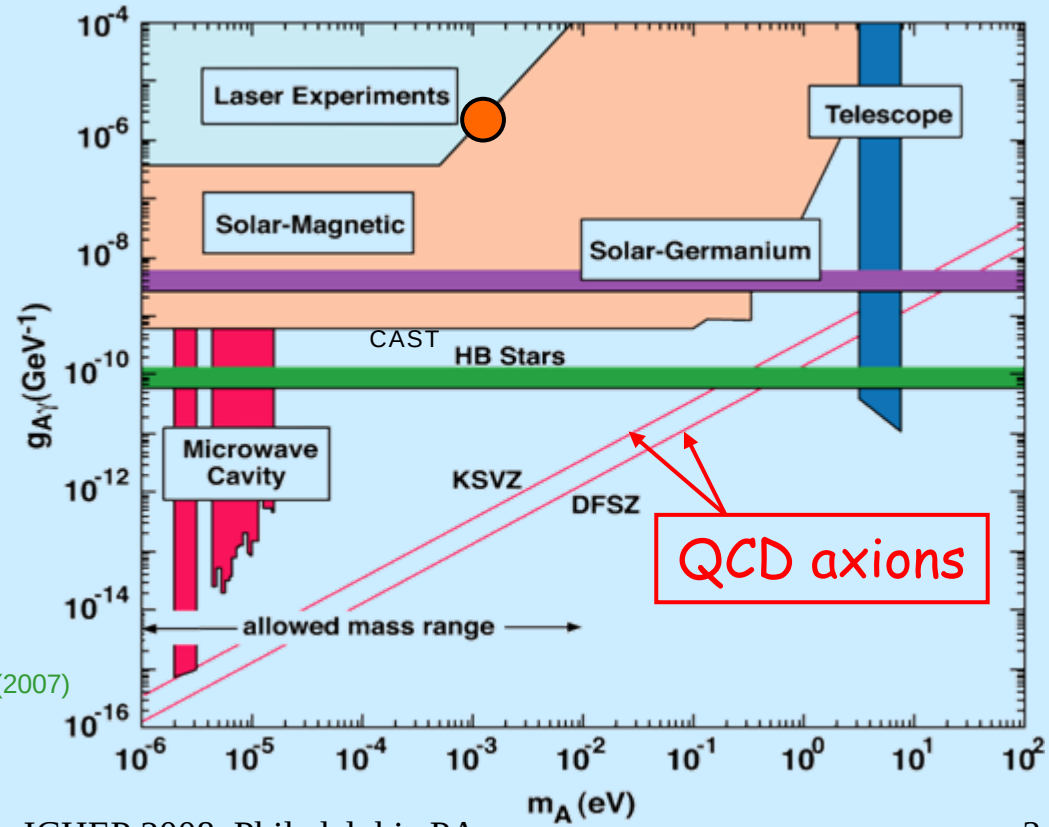
Energy frontier
Neutrinos
Astrophysics
all in one!

PVLAS Anomalies

In 2006, the PVLAS experiment reported an observation that linearly polarized light rotated in the presence of a magnetic field. Later at ICHEP 2006, PVLAS reported circularly polarized light developed an ellipticity. These observations were consistent with an axion-like particle with a mass ~1.2 meV and photon coupling ~2×10^{-6}. New data->no anomaly.



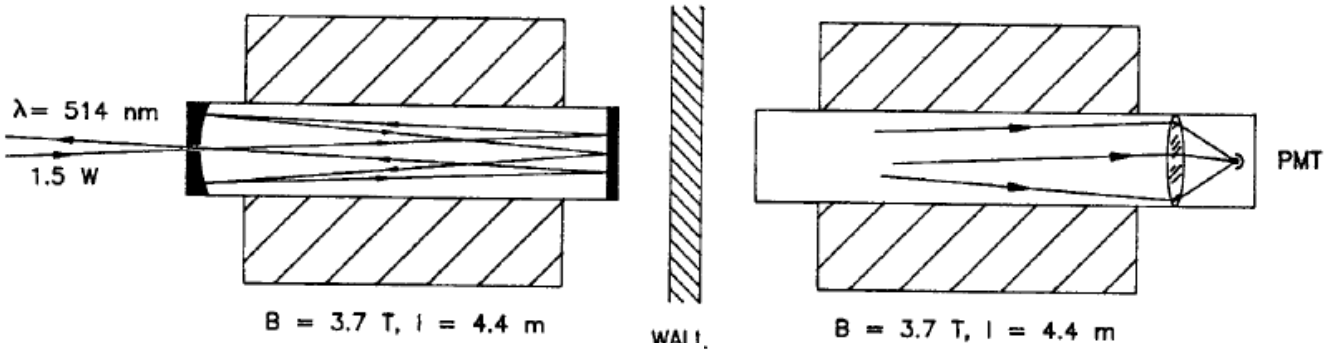
PRD **75**, 035011 (2007)

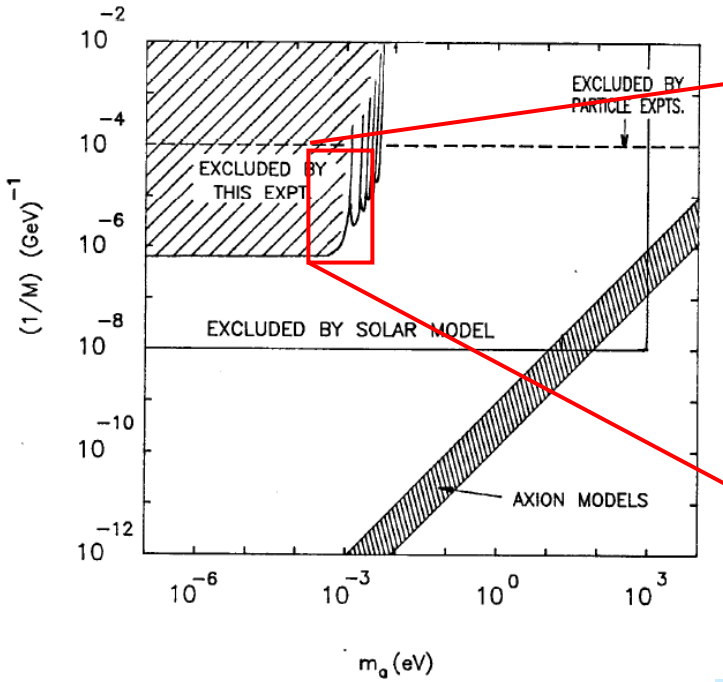


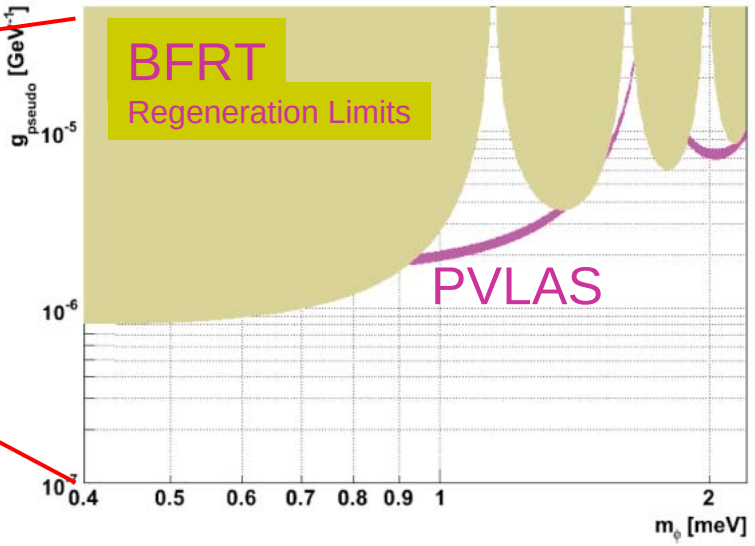
PVLAS rotation anomaly reported: PRL **96**, 110406 (2006)
PVLAS ellipticity anomaly reported: Nucl. Phys. Proc. Suppl. **174,** 233 (2007)
PVLAS anomalies go away with new data: arXiv:0706.3419 (2007)

Previous laser experiment

- Brookhaven, Fermilab, Rochester, Trieste (1992)

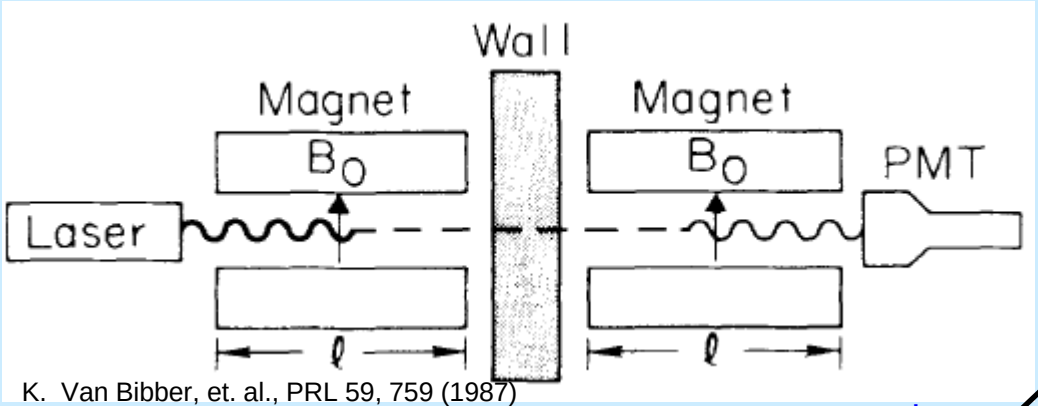




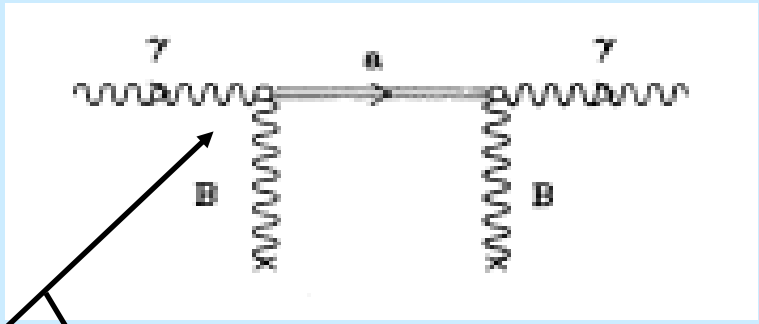


BFRT is not sensitive in the PVLAS region of interest.

Light Shining Through a Wall Experiment



K. Van Bibber, et. al., PRL 59, 759 (1987)



scalar

$$\mathcal{L}_{\rm int} = -\frac{1}{4}\frac{\phi}{M}F_{\mu\nu}F^{\mu\nu} = \frac{\phi}{M}(\vec{E}\cdot\vec{E} - \vec{B}\cdot\vec{B})$$

pseudoscalar

$$\mathcal{L}_{\rm int} = -\frac{1}{4}\frac{\phi}{M}F_{\mu\nu}\tilde{F}^{\mu\nu} = \frac{\phi}{M}(\vec{E}\cdot\vec{B})$$

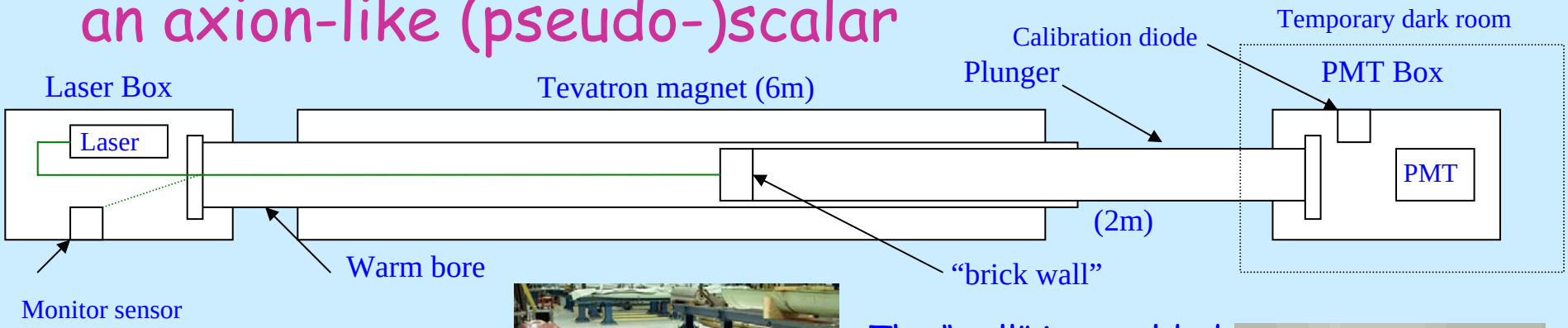
$$P_{regen} = \frac{16B_1^2B_2^2\omega^4}{M^4m_\phi^8}\sin^2\left(\frac{m_\phi^2L_1}{4\omega}\right)\cdot\sin^2\left(\frac{m_\phi^2L_2}{4\omega}\right)$$

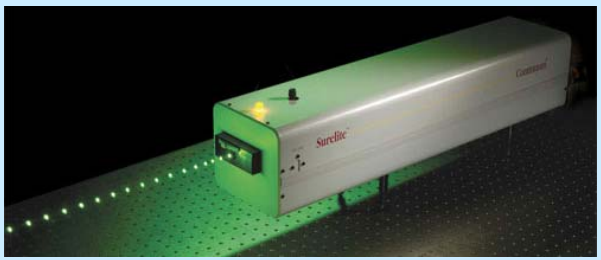
Assuming 5T magnet, the PVLAS "signal", and 532nm laser light

$$P_{regen}^{GammeV} = (3.9\times10^{-21})\times\frac{(B_1/5\text{ T})^2(B_2/5\text{ T})^2(\omega/2.33\text{ eV})^4}{(M/4\times10^5\text{ GeV})^4(m_\phi/1.2\times10^{-3}\text{ eV})^8}$$
$$\times\sin^2\left(\frac{\pi}{2}\frac{(m_\phi/1.2\times10^{-3}\text{ eV})^2(L_1/2.0\text{ m})}{(\omega/2.33\text{ eV})}\right)\sin^2\left(\frac{\pi}{2}\frac{(m_\phi/1.2\times10^{-3}\text{ eV})^2(L_2/2.0\text{ m})}{(\omega/2.33\text{ eV})}\right)$$

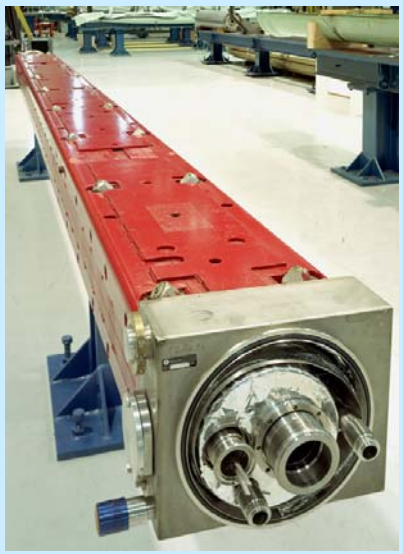
GammeV Proposal

Search for evidence of a milli-eV particle in a light shining through a brick wall experiment to unambiguously test the PVLAS interpretation of an axion-like (pseudo-)scalar

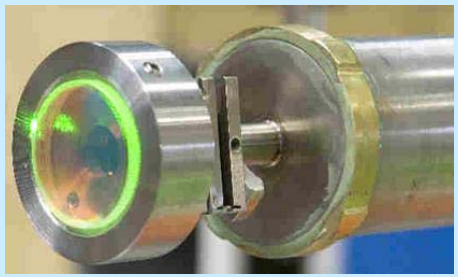




Existing laser used by the Accelerator Division.



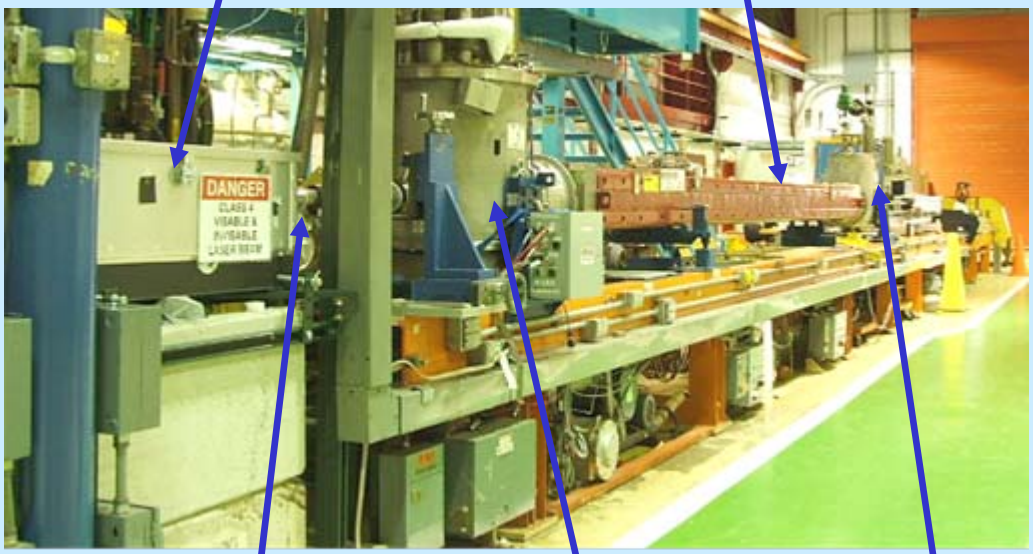
The "wall" is a welded steel cap on a steel tube in addition to a reflective mirror.

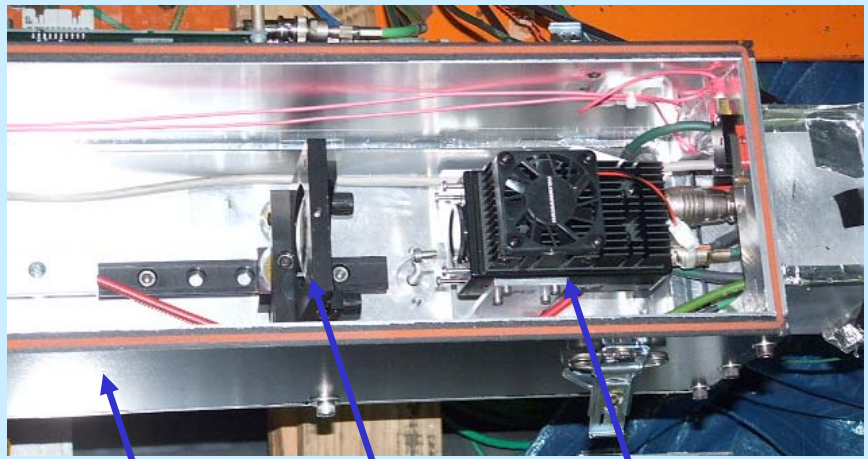


High-QE, low noise, fast PMT module (purchased)

Apparatus

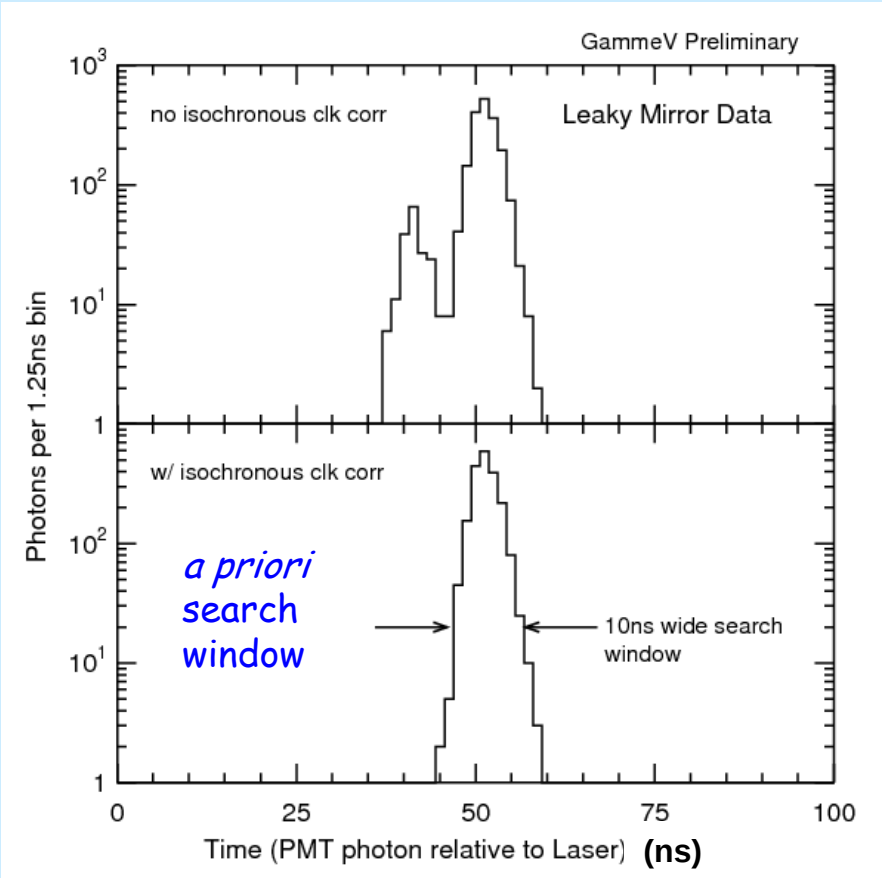
GammeV was located on a test stand at Fermilab's Maget Test Facility. Two shifts/day of cryogenic operations were supported.

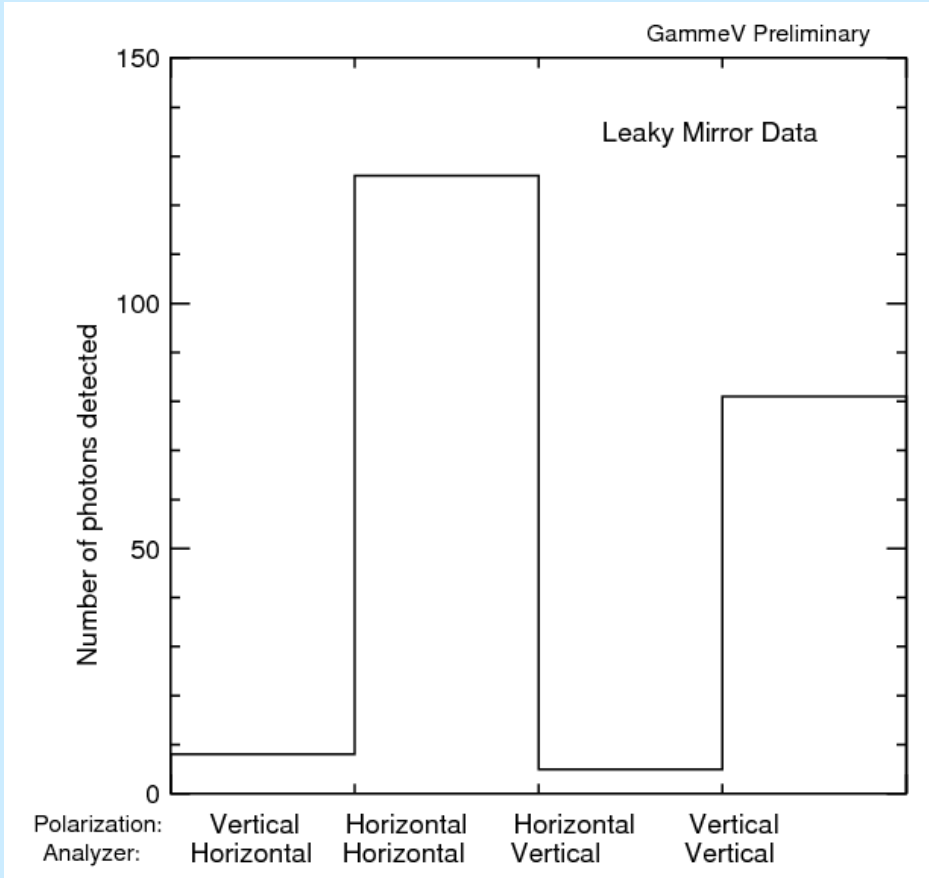




GammeV Calibration

- Very little background using time correlated single photon counting between the laser pulses and the PMT pulses (correct 10ns jitter).
- Use "Leaky Mirror" data (attenuate laser light to single photons) to verify both the absolute timing and the sensitivity to polarization.



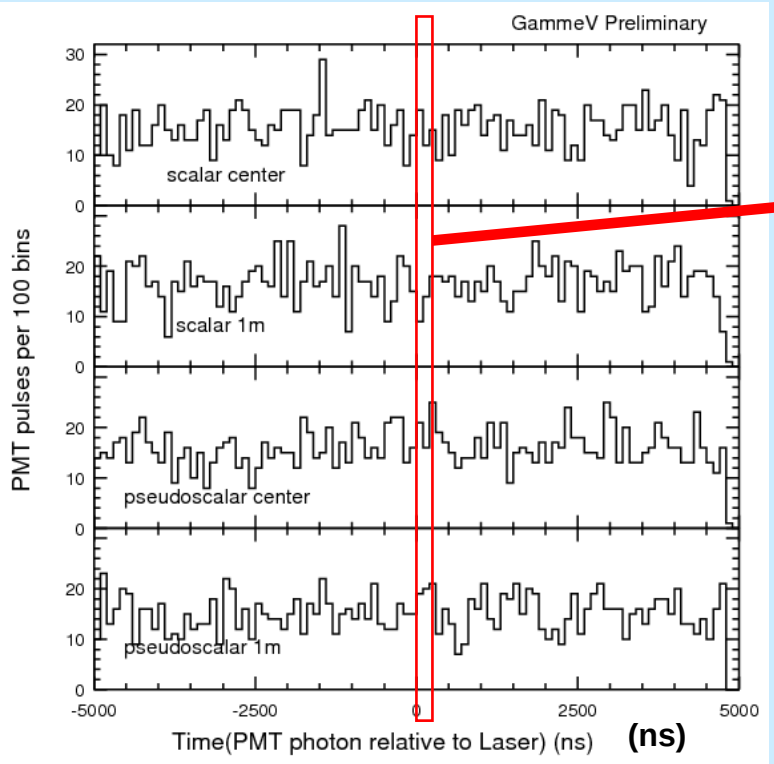


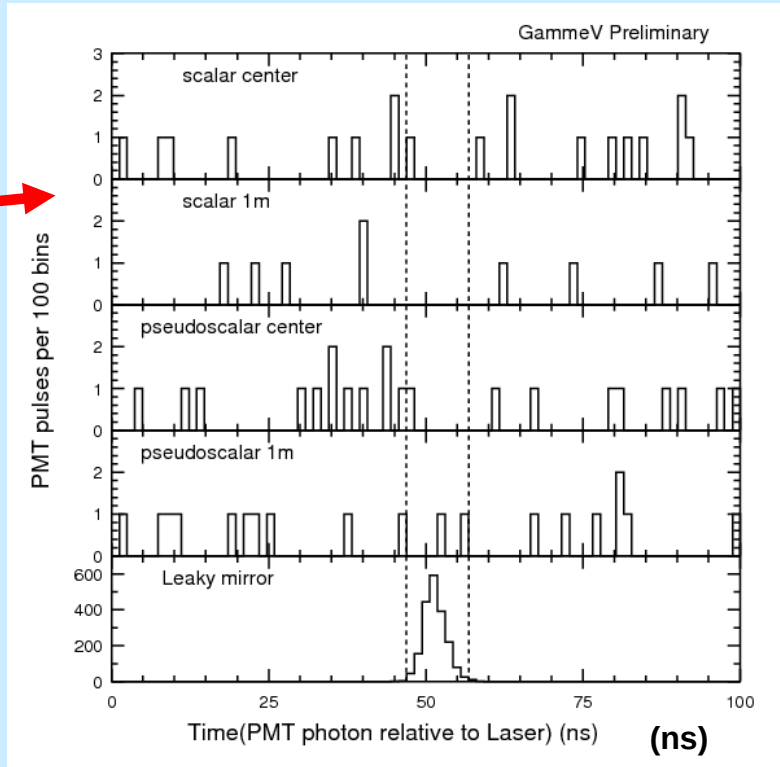
GammeV Method

- Take data in four configurations
  - Scalar (with $\frac{1}{2}$-wave plate) with the plunger in the center and at 1m
  - Pseudoscalar also with the plunger in the center and 1m positions
- In each configuration, acquire about 20 hours of magnet time or about 1.5M laser pulses at 20Hz.
  - Monitor the power of the laser using a power meter that absorbs the laser light reflected back into the laser box using NIST traceable calibration to +/-3%
- Total efficiency (25 +/- 3)%
  - PMT detection efficiencies from factory measurements QE x CE 39% x 70% = 27%
  - Measured attenuation in BK7 windows and lens: 92%
- Background in a 10ns wide search region is estimated by counting the events in a 10,000ns wide window around all the laser pulses and dividing by 1000.

GammeV Data

Spin	Position	# Laser pulse	# photon / pulse	Expected Background	Signal Candidates
Scalar	Center	1.34 M	0.41e18	1.56±0.04	1
Scalar	1 m	1.47M	0.38e18	1.67±0.04	0
Pseudo	Center	1.43M	0.41e18	1.59±0.04	1
Pseudo	1m	1.47M	0.42e18	1.50±0.04	2

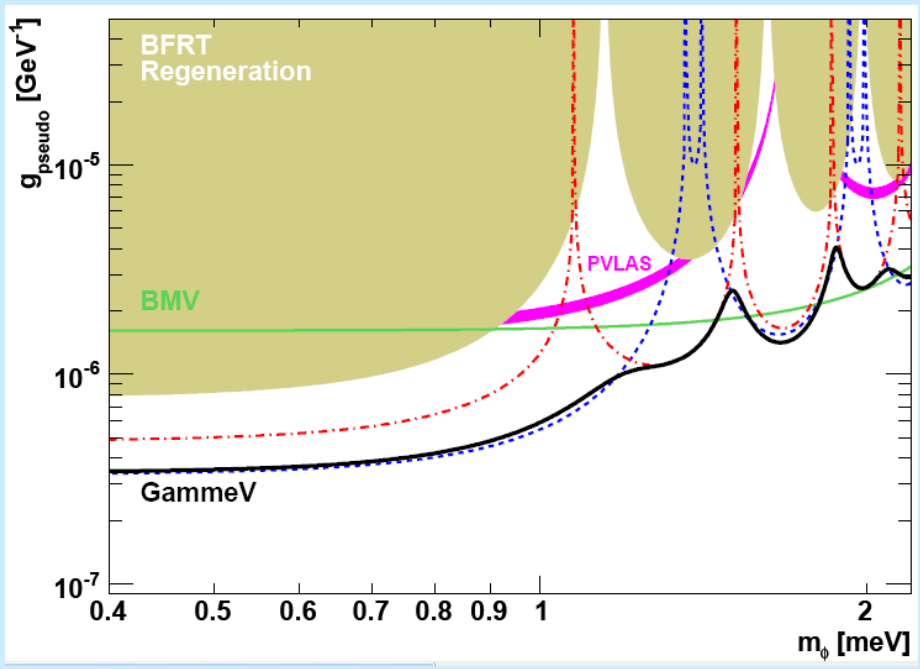




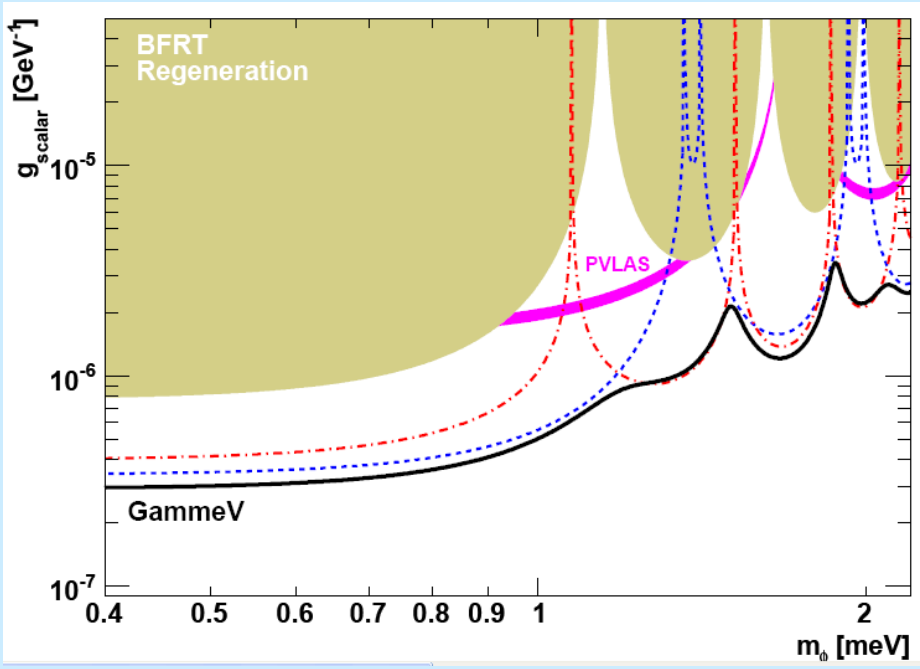
GammeV Results

- Results are derived. We show **3σ** exclusion regions and completely rule out the PVLAS axion-like particle interpretation by more than **5σ**.

Pseudoscalar



Scalar

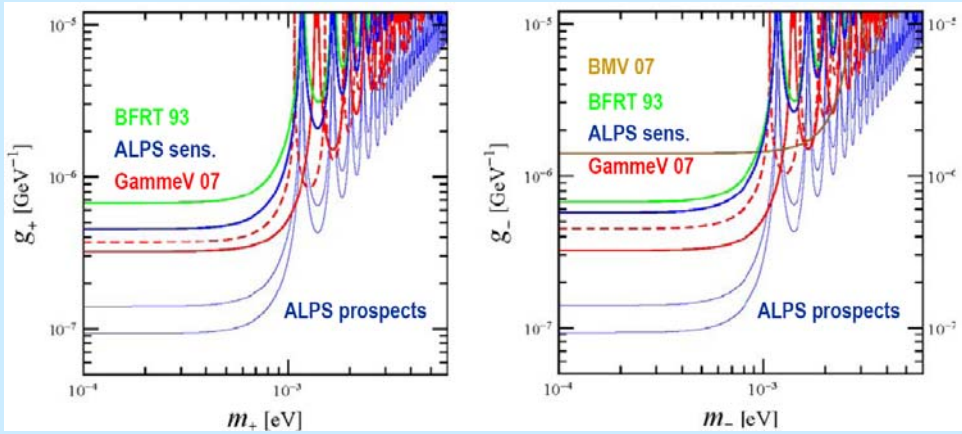


PRL **100**, 080402 (2008)

Proposed in April 2007, PRL in January 2008!

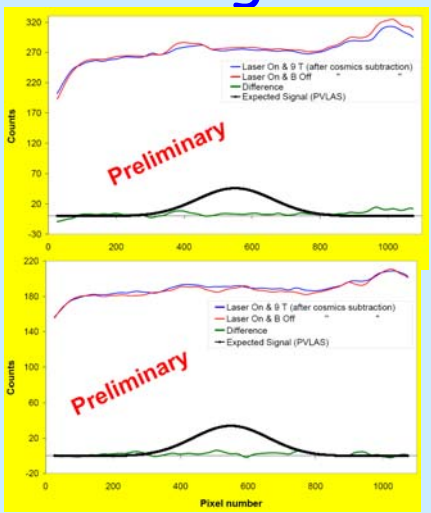
Other experiments

- 4th Patras Workshop on Axions, WIMPs, and WISPs
  - DESY, June 2008
  - web: axion-wimp.desy.de
- No evidence of axion-like particles using different configurations of LSW technique.



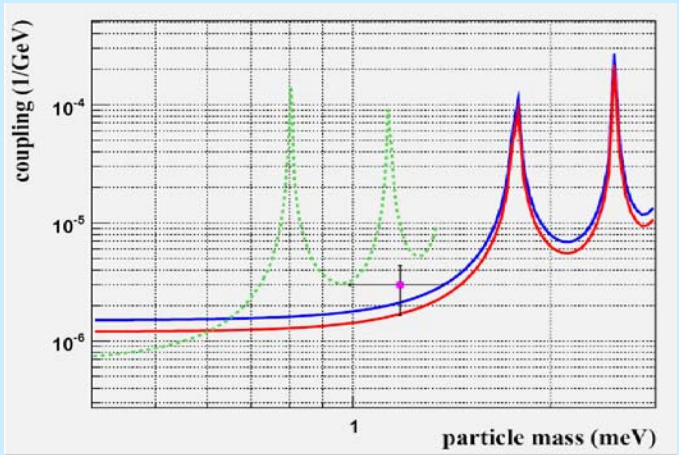
ALPS

conferences



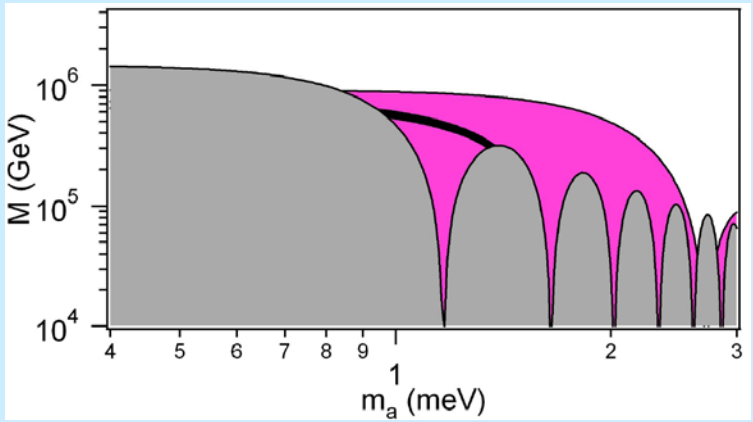
OSQAR

hep-ex/0712.3362
Note: with N_2 gas



LIPSS

scalar only
arXiv:0806:2631

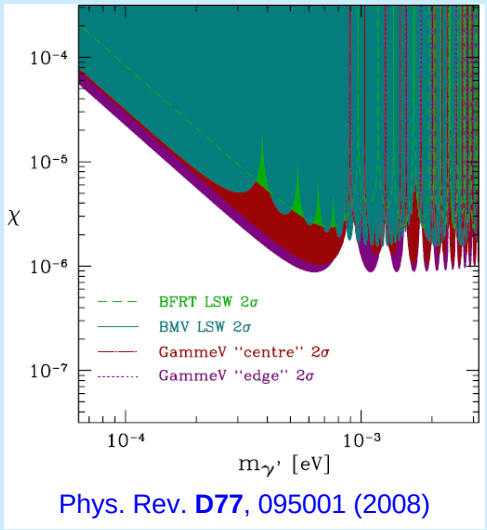


BMV

pseudoscalar only
Final results submitted to PRD
1st results: PRL **99**, 190403 (2007)

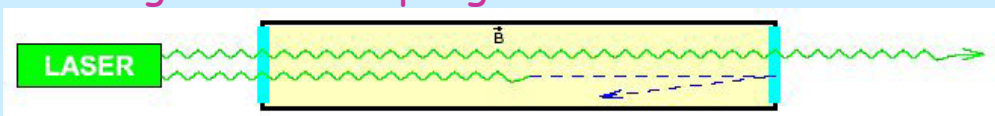
Other GammeV results

- GammeV results set limits on the mixing parameter for photons to oscillate into massive paraphotons that might arise from a new U(1) symmetry.
- GammeV took data in a "particle in a jar" configuration to set first ever limits on *chameleon* particles.

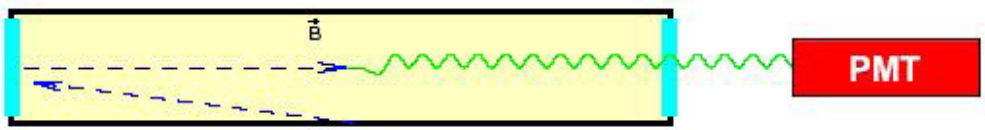


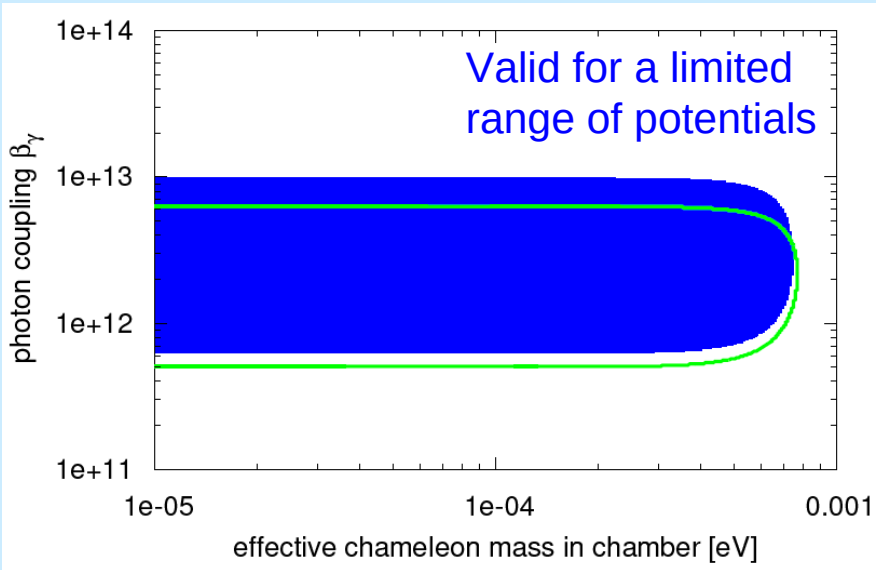
Phys. Rev. **D77**, 095001 (2008)

Generate 100% reflective chameleons due to strong matter coupling.



Turn off laser and look for a regenerated photon afterglow.

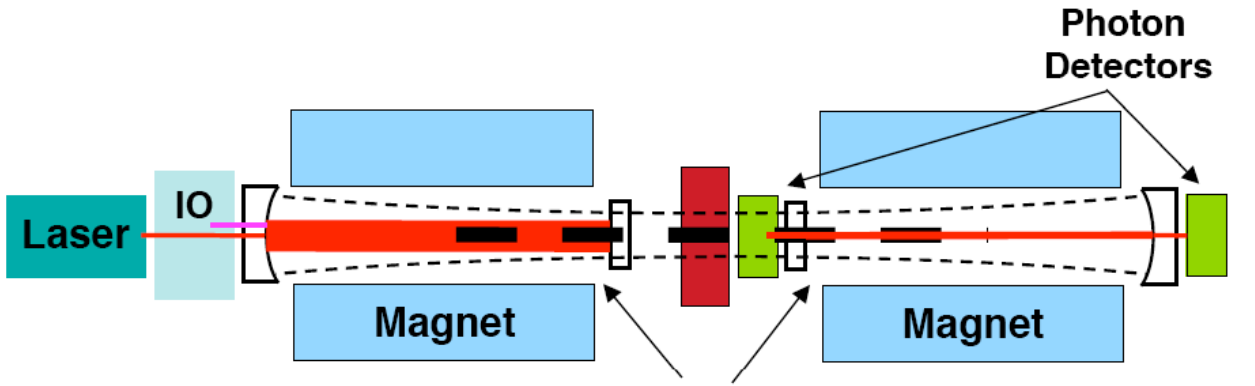




arXiv:0806.2438

Next future steps?

Resonantly enhanced axion-photon regeneration

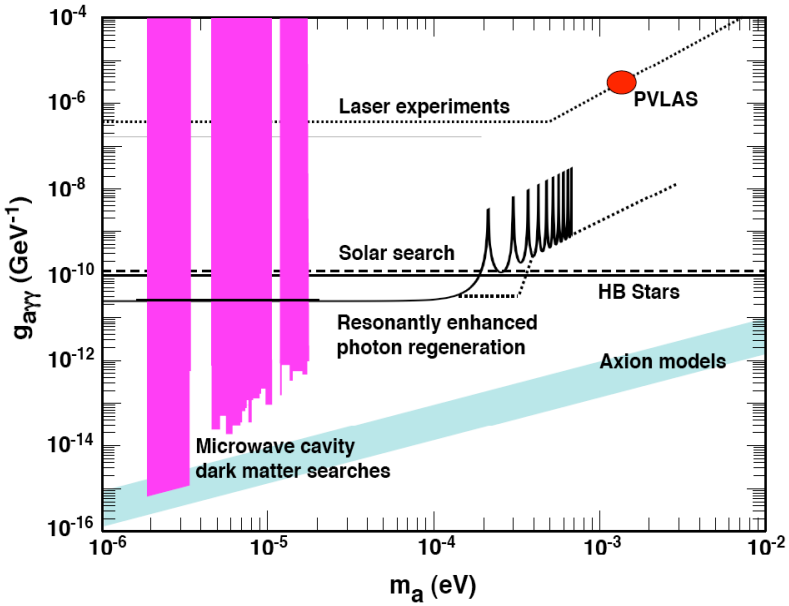


Sikivie, Tanner, van Bibber
Phys. Rev. Lett. **98**, 172002 (2007)

Probability of regeneration goes as the product of finesse's: $\mathcal{FF}$

Possibility that this technique might exceed star cooling and CAST (AM talk today) limits.

Note that microwave cavity experiments (ADMX) are now probing the QCD axion.



Conclusion

- At FNAL, a small group of us had fun one summer ago. There were days going into work thinking today *might* be the day that a new revolutionary particle might appear.
- We probed the milli-eV region of interest for axion-like particles with and set new interesting limits
- Results obtained on paraphotons and other weakly interacting sub-eV particles (WISPs) like chameleons
- Finally, just like there are theories that are "Not Yet Thought Of", so there are also opportunities for such experiments.