

Gamma meV

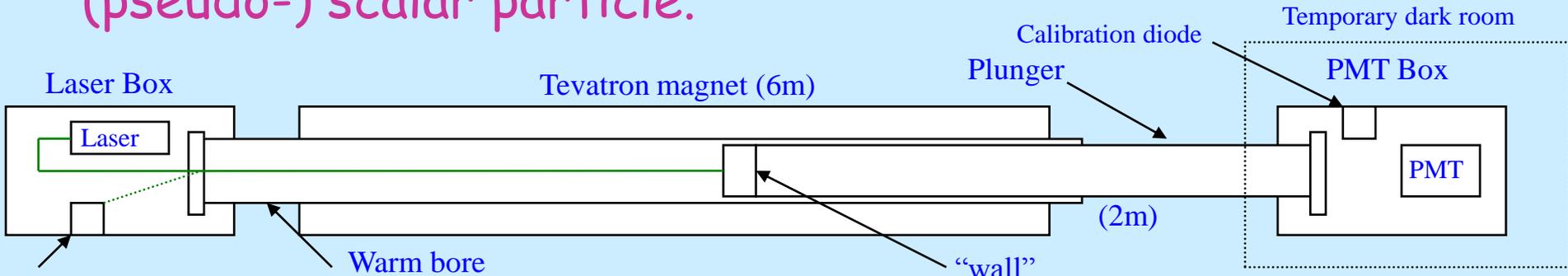
Gamma to milli-eV particle search

Results and Future Plans
at Fermilab

William Wester
Fermilab

GammeV Design

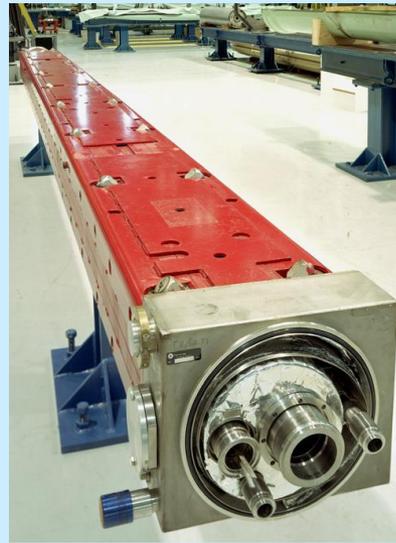
Search for evidence of a milli-eV particle in a light shining through a wall experiment (simple, quick, inexpensive) to test the 2006 PVLAS interpretation of an axion-like (pseudo-) scalar particle.



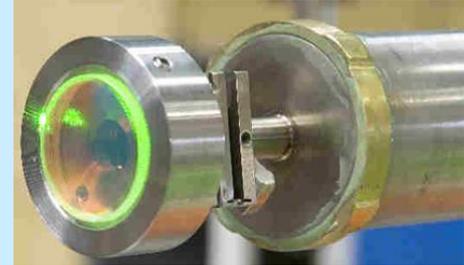
Monitor sensor



Existing laser in Acc. Div. nearly identical with a similar spare available



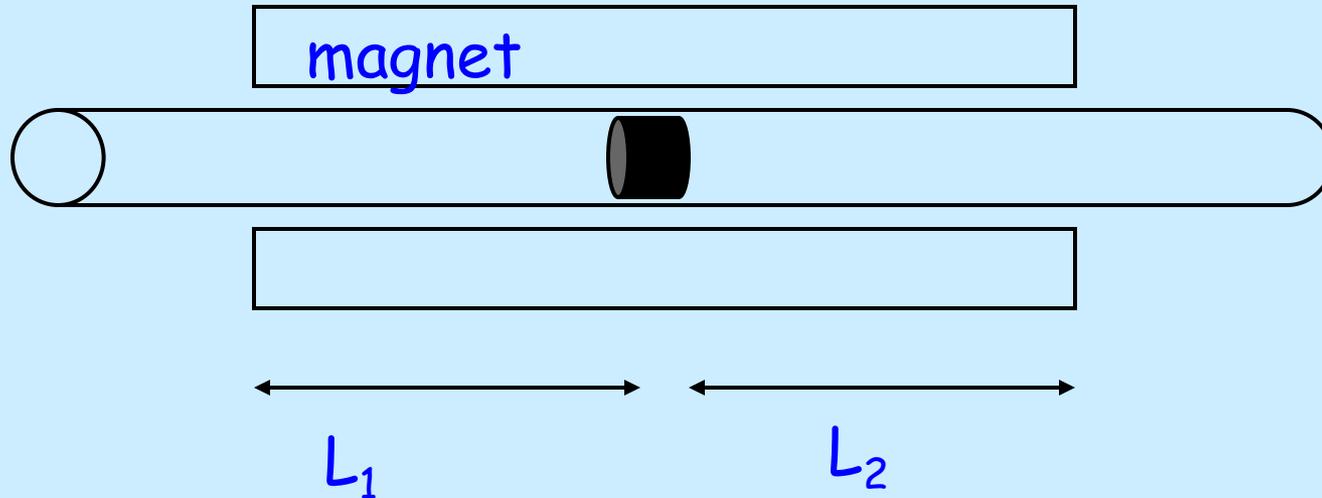
The "wall" is a welded steel cap on a steel tube in addition to a reflective mirror.



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

Vary wall position to change baseline:
Tune to the correct oscillation length

A unique feature of our proposal to cover larger m_ϕ range



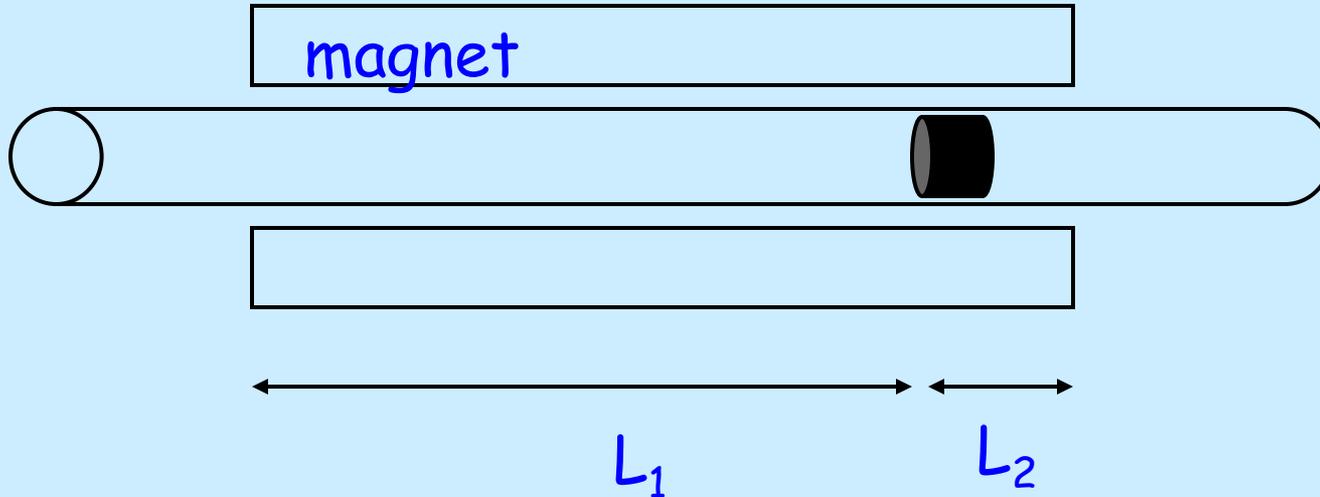
$$P_{\gamma \rightarrow \phi} = \frac{4B^2 \omega^2}{M^2 (\Delta m^2)^2} \left(\sin \frac{\Delta m^2 L}{4\omega} \right)^2$$

$L =$ distance traversed in B field

$$P_{\text{regen}} = \left(\frac{4B^2 \omega^2}{M^2 (\Delta m^2)^2} \right)^2 \left(\sin \frac{\Delta m^2 L_1}{4\omega} \right)^2 \left(\sin \frac{\Delta m^2 L_2}{4\omega} \right)^2$$

Vary wall position to change baseline:
Tune to the correct oscillation length

A unique feature of our proposal to cover larger m_ϕ range

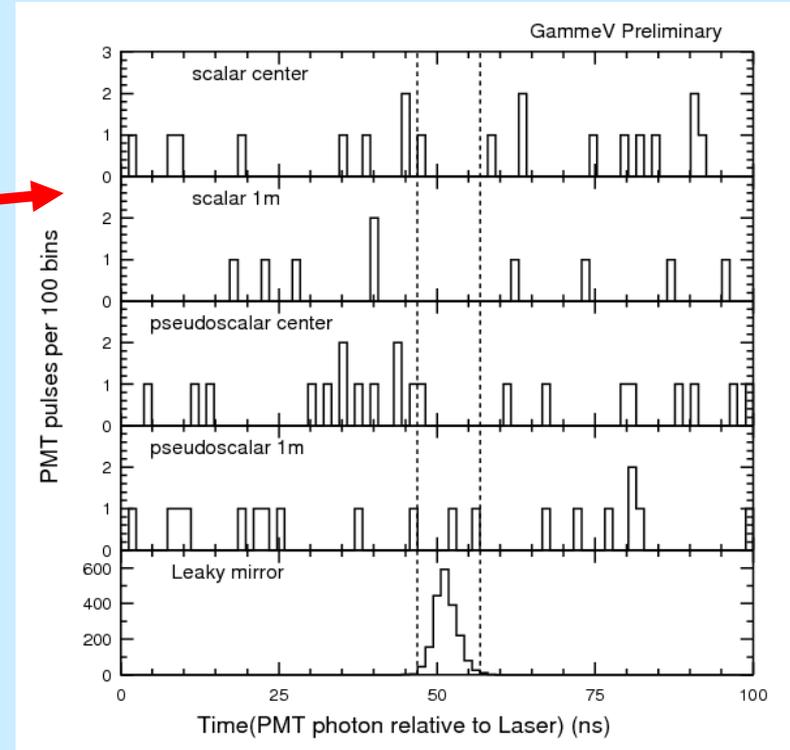
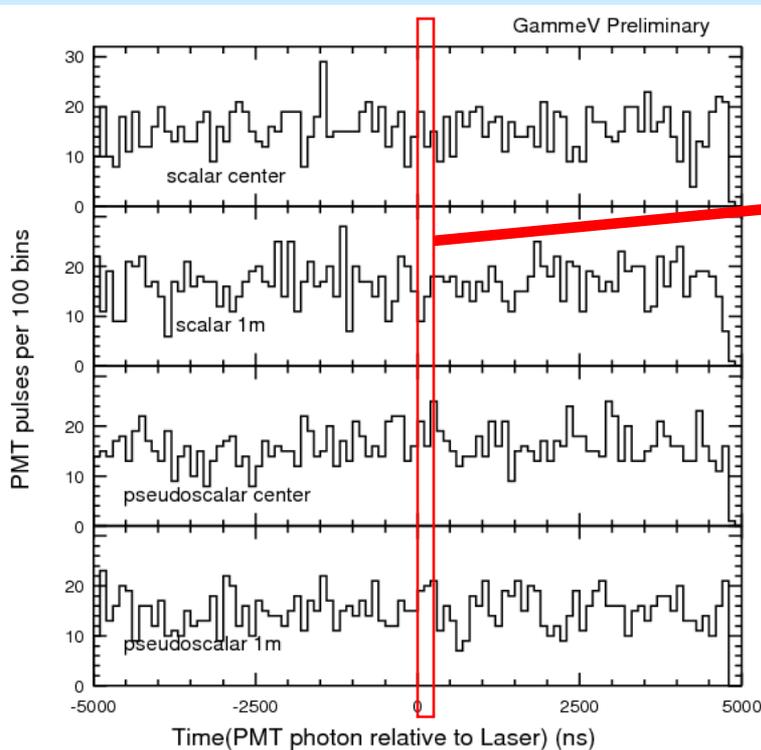


$$P_{\gamma \rightarrow \phi} = \frac{4B^2 \omega^2}{M^2 (\Delta m^2)^2} \left(\sin \frac{\Delta m^2 L}{4\omega} \right)^2 \quad L = \text{distance traversed in B field}$$

$$P_{\text{regen}} = \left(\frac{4B^2 \omega^2}{M^2 (\Delta m^2)^2} \right)^2 \left(\sin \frac{\Delta m^2 L_1}{4\omega} \right)^2 \left(\sin \frac{\Delta m^2 L_2}{4\omega} \right)^2$$

GammeV Results

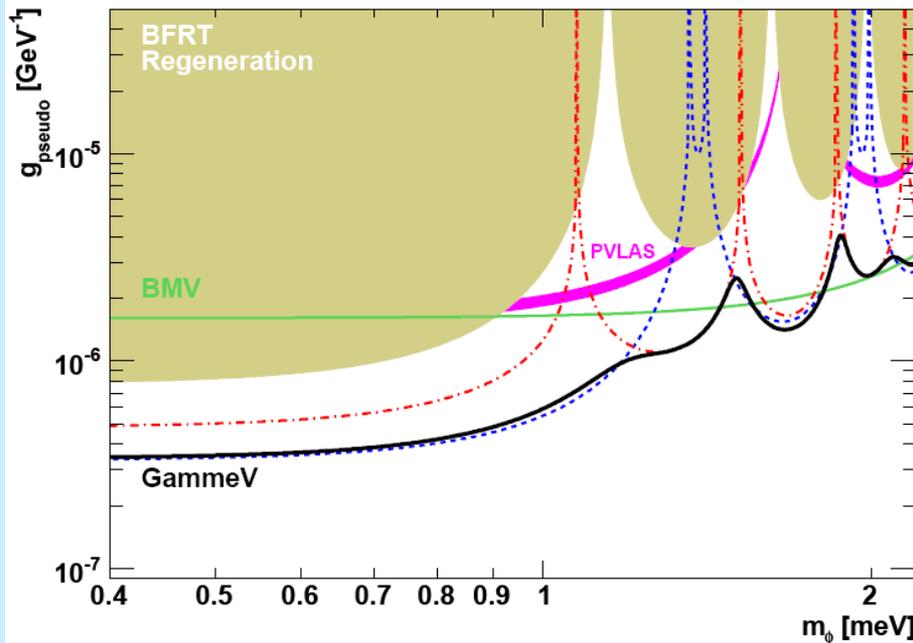
Spin	Position	# Laser pulse	# photon / pulse	Expected Background	Signal Candidates
Scalar	Center	1.34 M	0.41e18	1.56±0.04	1
Scalar	1 m	1.47M	0.38e18	1.67±0.04	0
Pseudo	Center	1.43M	0.41e18	1.59±0.04	1
Pseudo	1m	1.47M	0.42e18	1.50±0.04	2



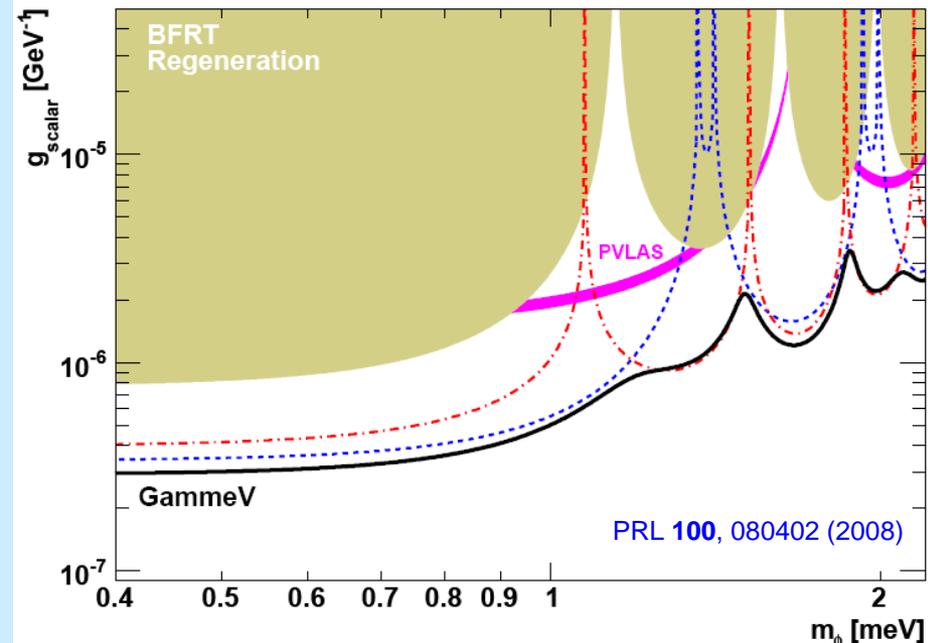
GammeV Limits

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

Pseudoscalar



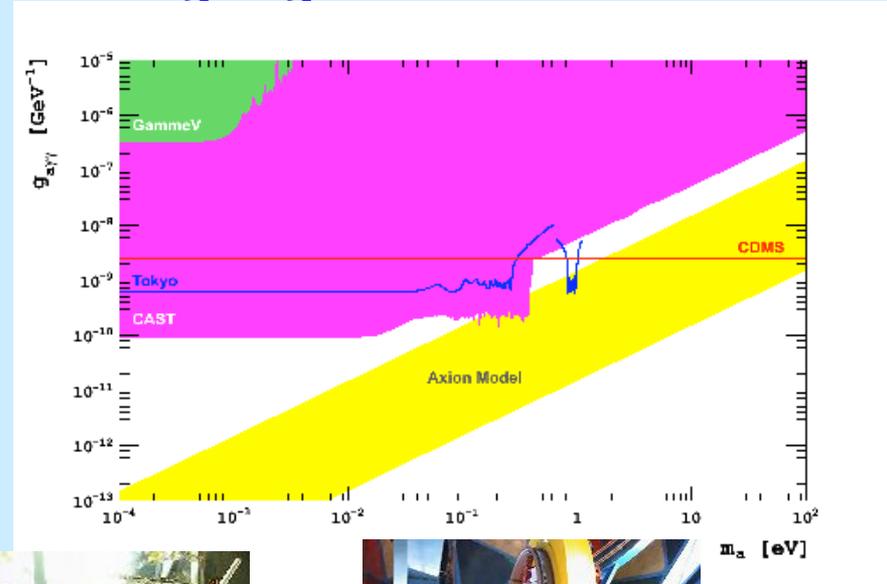
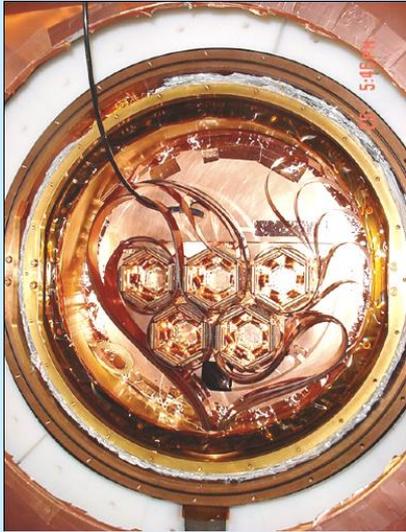
Scalar



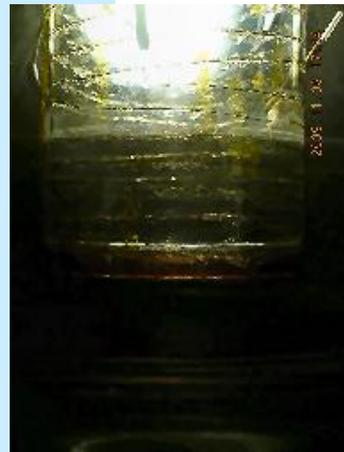
- Job is done. Limit would generally improve as the 4th root of longer running time, or increased laser power, etc.

Bragg scattering

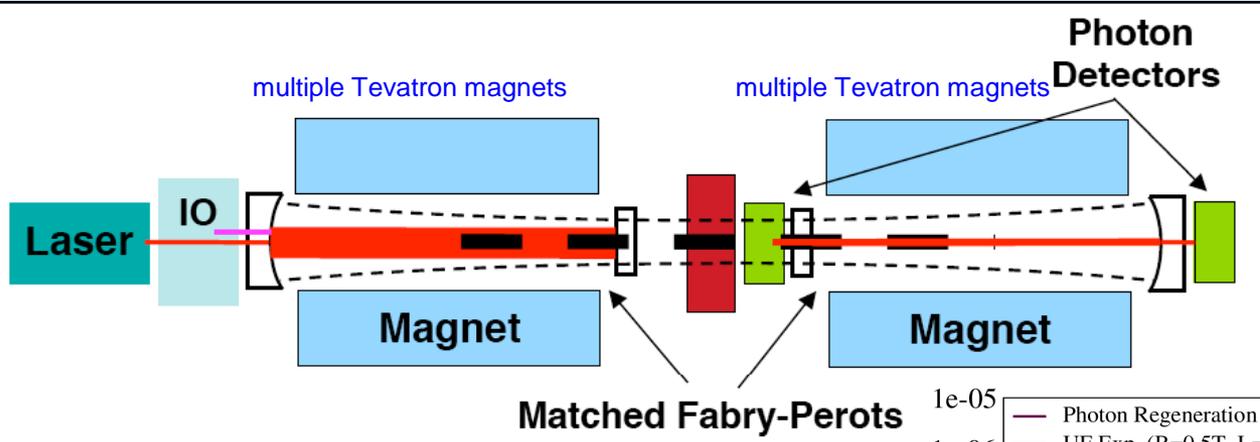
- Use CDMS crystals with known alignment towards the sun. Search for coherent scattering signal of ALPs.



- R&D w/solid Xenon
- Maybe use telescope simulator for Dark Energy Survey Camera



Resonantly enhanced axion-photon regeneration

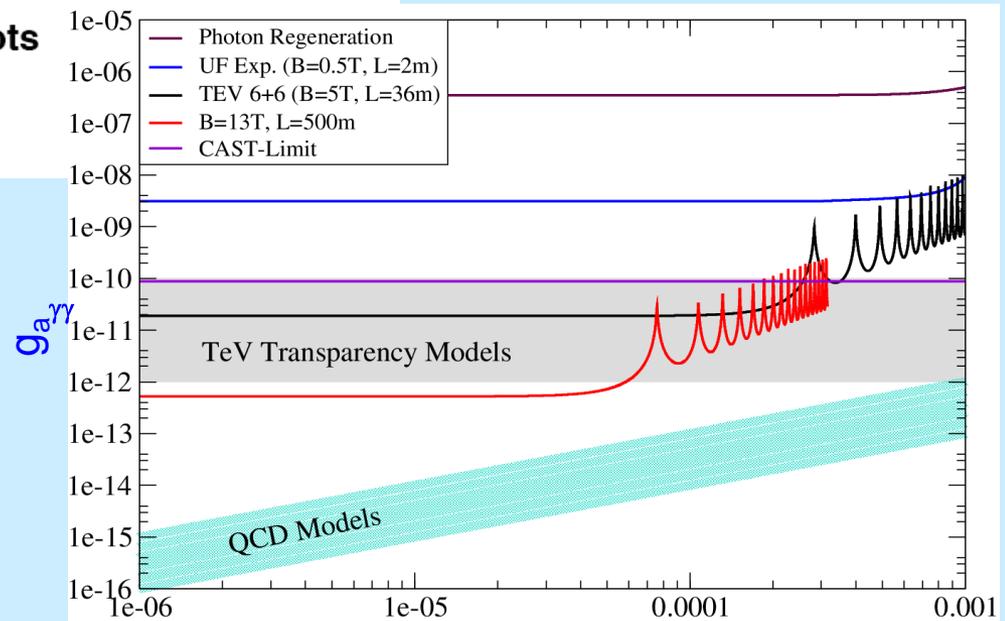


Probability of regeneration goes as the product of finesse's: FF

F. Hoogeveen and T. Ziegenhagen, Nucl. Phys. B **358**, 3 (1991)
 Mueller, Sikivie, Tanner, van Bibber, Phys. Rev. D **80**, 072004 (2009)
 Phys. Rev. Lett. **98**, 172002 (2007)

Possibility that this technique might exceed star / CAST limits.

Hints that a coupling of 10^{-11} might be interesting from observations of unexpected high energy gamma rays that somehow propagate despite background IR photons.



Plans

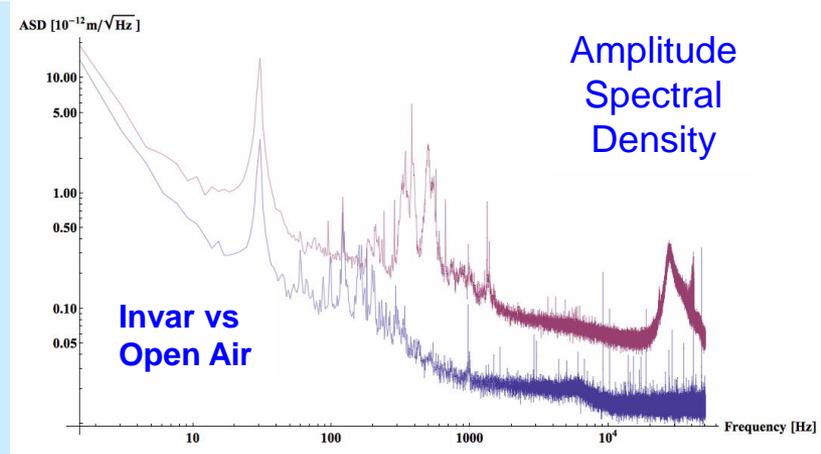
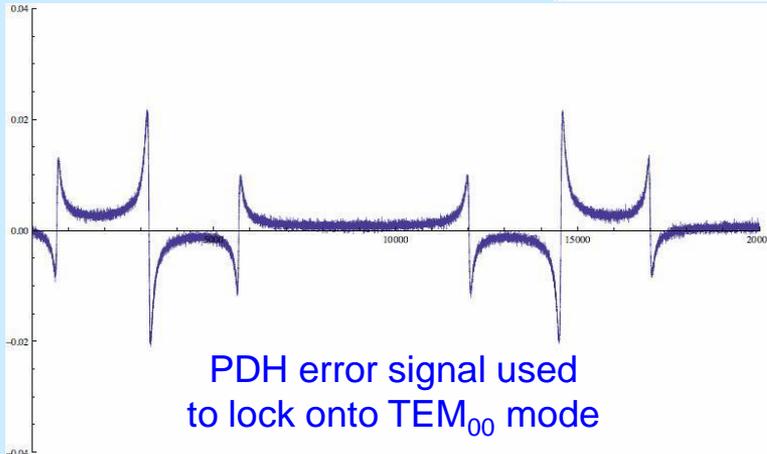
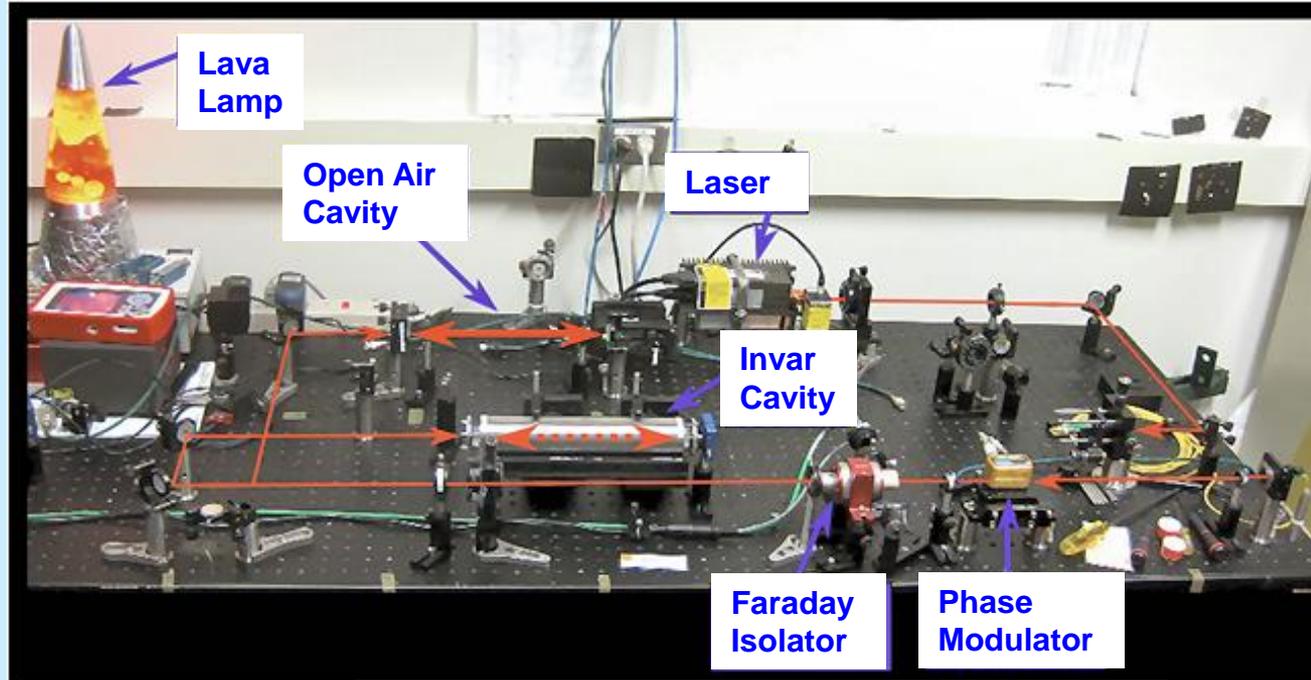
- Fermilab - develop the requirements and expected performance of long cavities and determine the scope of using a long string of Tevatron magnets
 - 40m long cavity and specially coated mirrors
 - Accelerator Division informed of our plans. Status of the Tevatron to be determined.
- Univ of Florida - develop cavity locking scheme
 - Initial designs and concepts are being studied.
 - See talk by G. Mueller at Axion 2010
 - Preparing possible proposal (including graduate student) to develop the locking scheme and required control system and to perform a table top experiment using Fermilab supplied permanent magnets (0.5T).

Bench top preparations

Study by Bobby Lanza,
grad student Univ. of Chicago



Invar optical cavity
(commercial mirrors)



Chameleons

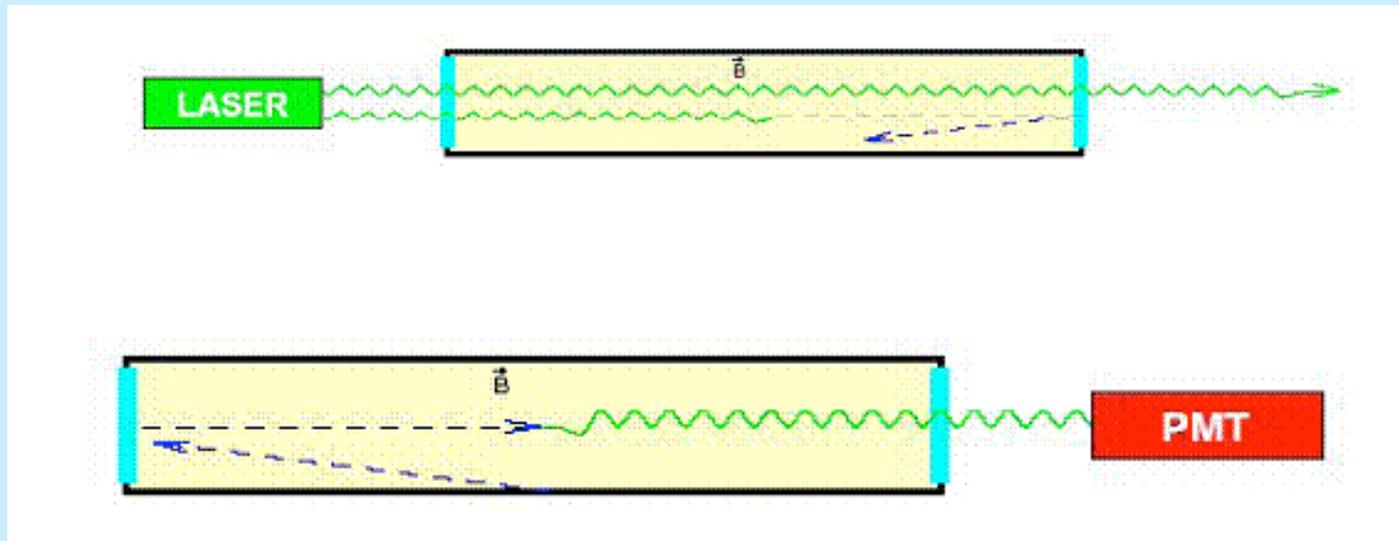
- An axion-like particle with the property that its properties depend on its environment. In particular, a coupling to the stress energy tensor and a non-trivial potential result in unique properties such as a mass that depends on the ambient matter density: $m_{\text{eff}} \sim \rho^\alpha$.

$$\mathcal{L}_{\text{int}} = -V(\phi) + \exp\left(\frac{\phi}{M_D}\right) g_{\mu\nu} T^{\mu\nu} - \frac{1}{4} \frac{\phi}{M} F_{\mu\nu} F^{\mu\nu}$$

- Such a field might evade fifth force measurements and could explain how there could be an axion-like particle with a strong photon coupling which evades other bounds.
- The chameleon mechanism (Khoury and Weltman) was originally postulated as a mechanism to account for the cosmic expansion.

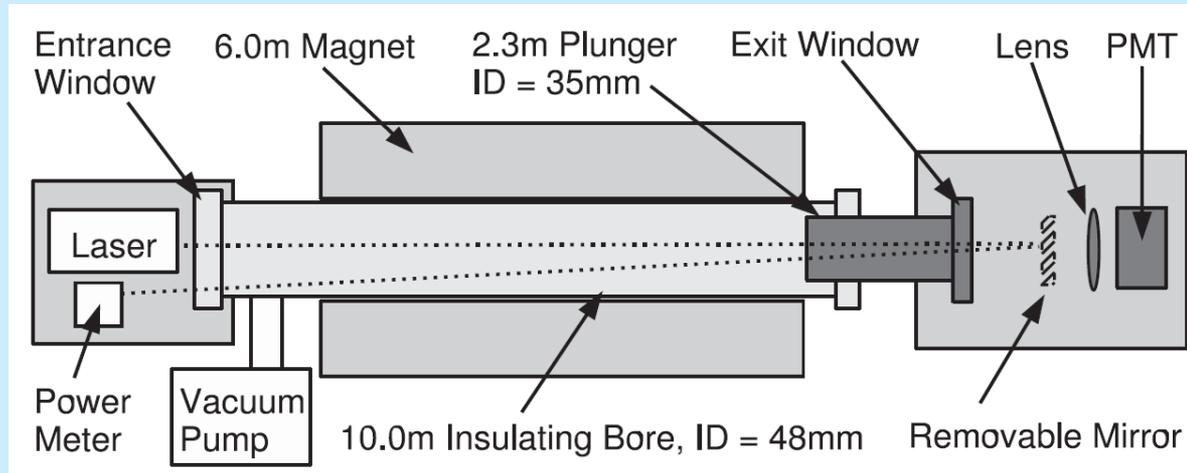
"Particle in a Jar"

- Chameleon properties depend on their environment - effective mass increases when encountering matter.
 - A laser in a magnetic field might have photons that convert into chameleons which reflect off of the optical windows. A gas of chameleons are trapped in a jar.
 - Turn off the laser and look for an afterglow as some of the chameleons convert back into detectable photons.



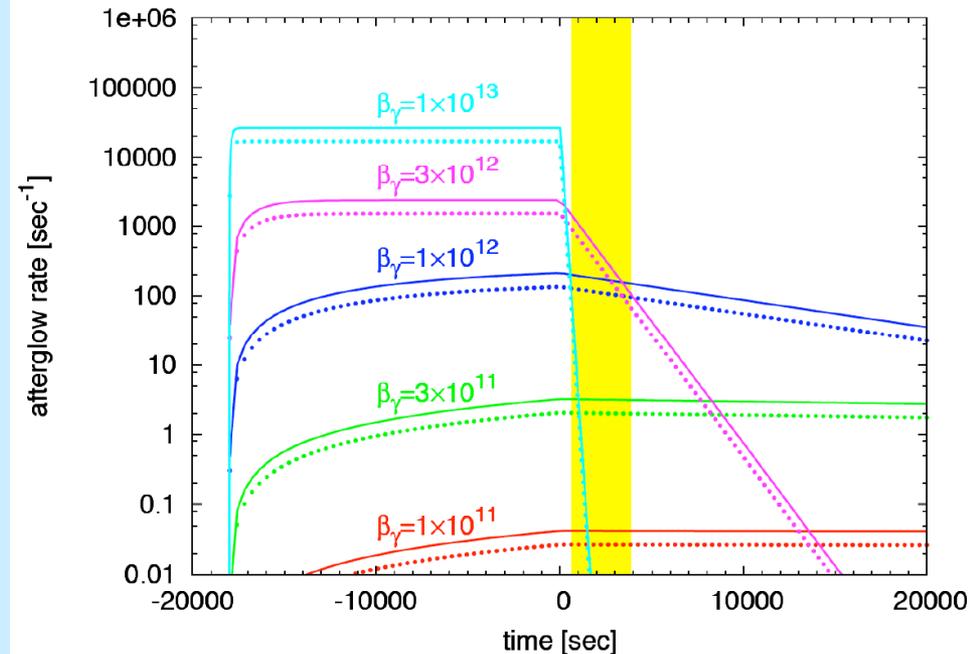
- GammeV Apparatus**

Replace the wall with a straight-through tube with an exit window



- Procedure**

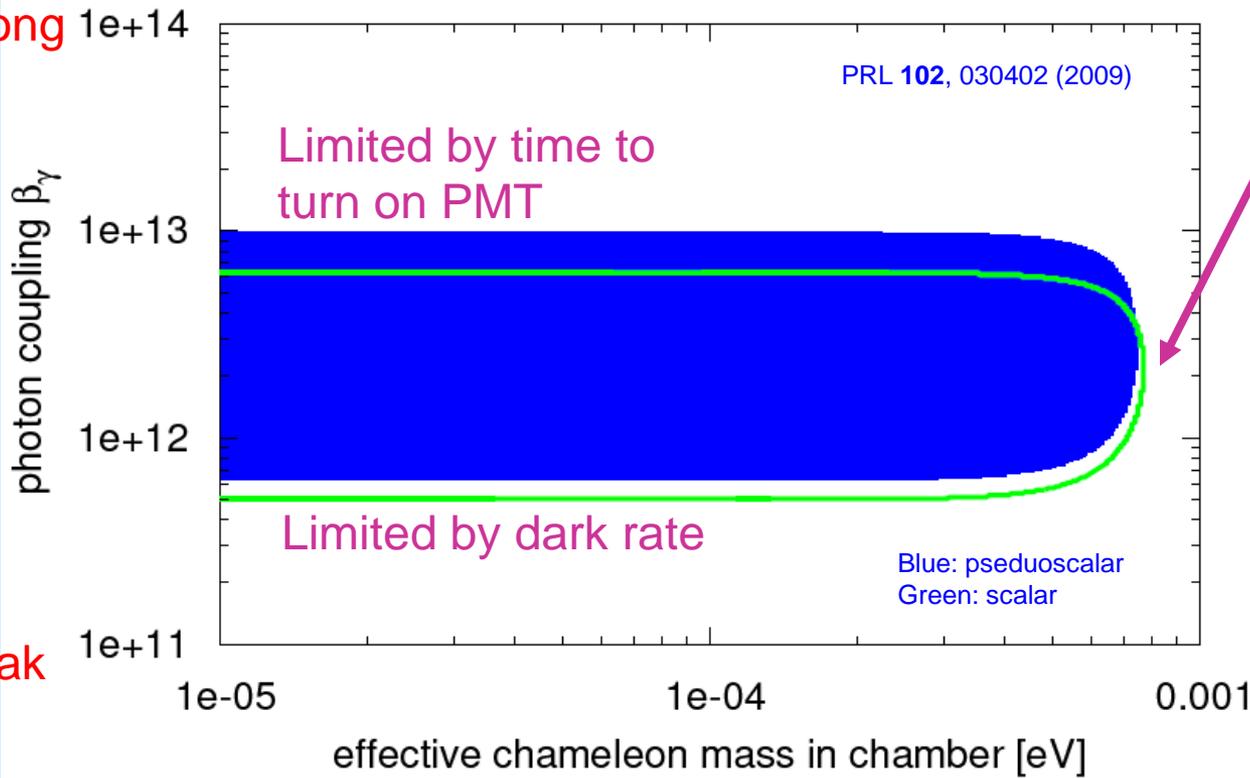
Turn on pulsed laser for 5hrs using both polarizations. Turn off laser and look for an afterglow above PMT dark rate, either constant or exponentially decaying depending on the photon coupling.



Chameleon Results

- Coupling of photons vs m_{eff} in a region of validity

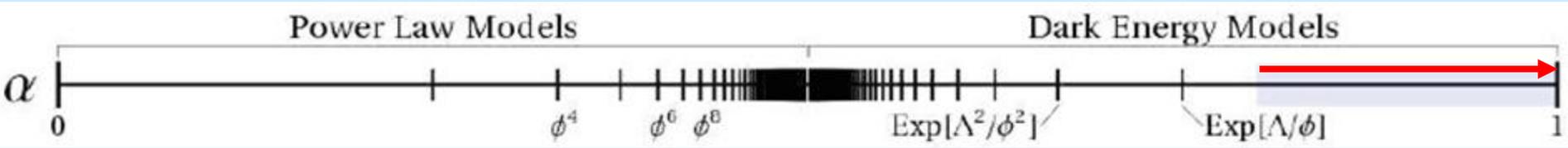
Strong



Reduced sensitivity at higher masses due to experimental configuration

Also, uncertainties in the vacuum levels limit sensitivity of possible potentials, with $m_{eff} \sim \rho^\alpha, > 0.8$.

Weak



New effort (2010)

- GammeV - CHASE: Chameleon Afterglow Search

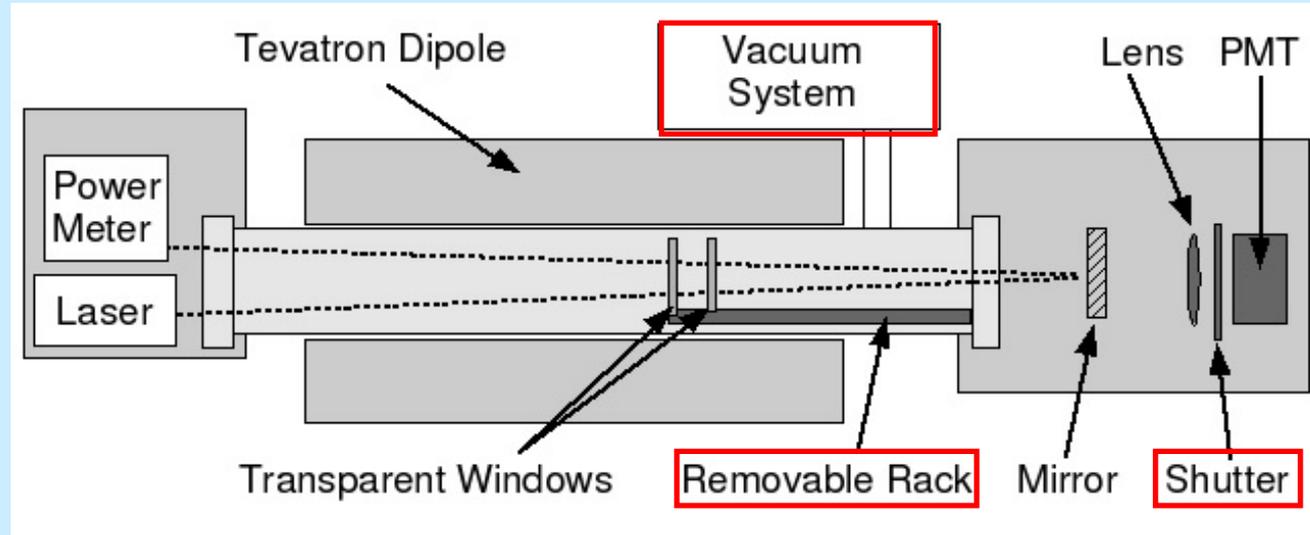
Improve vacuum (cryo pump) and monitoring.

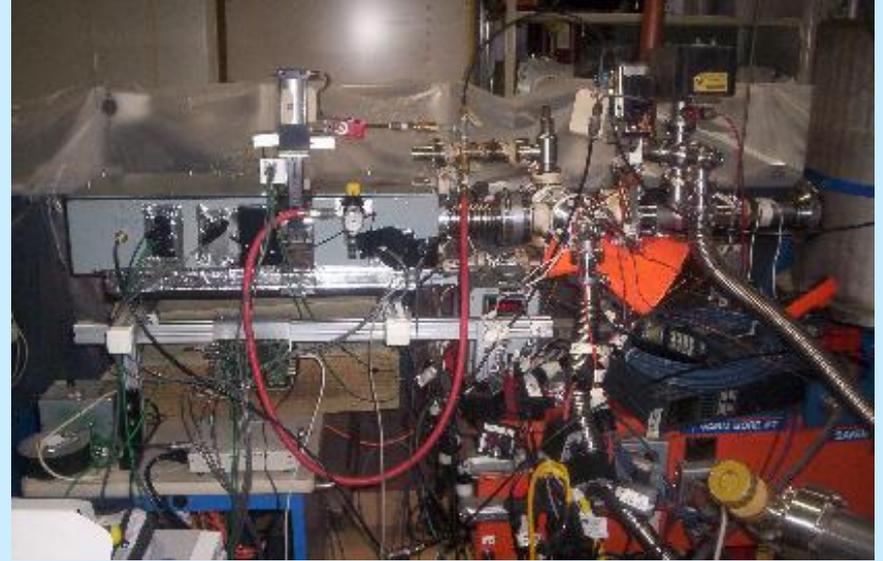
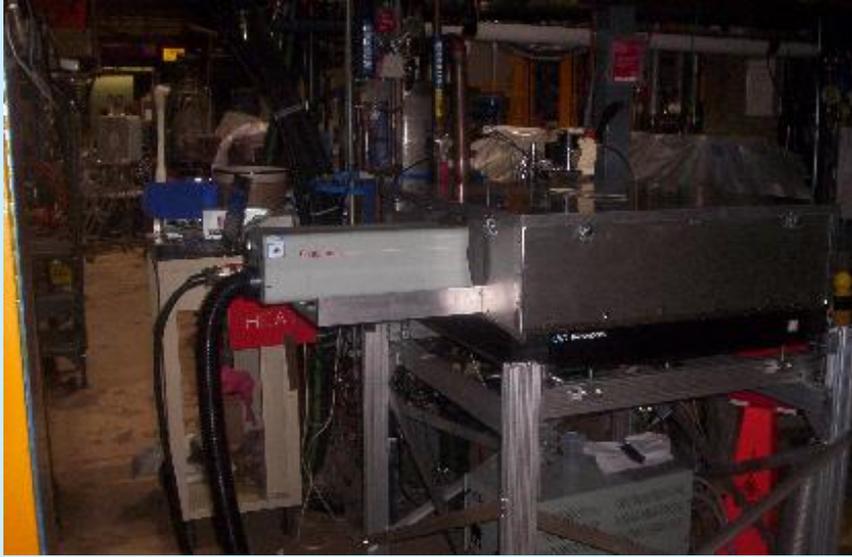
Use a shutter to switch to PMT readout quickly.

Use a run plan that with lower B fields in case the coupling is strong.

Use a lower noise PMT.

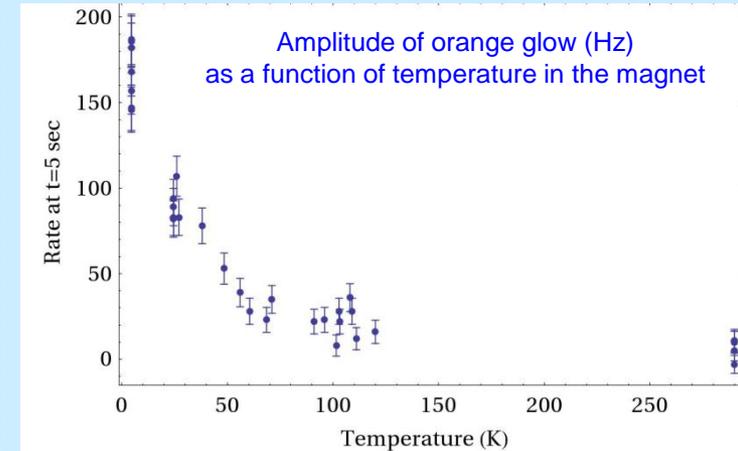
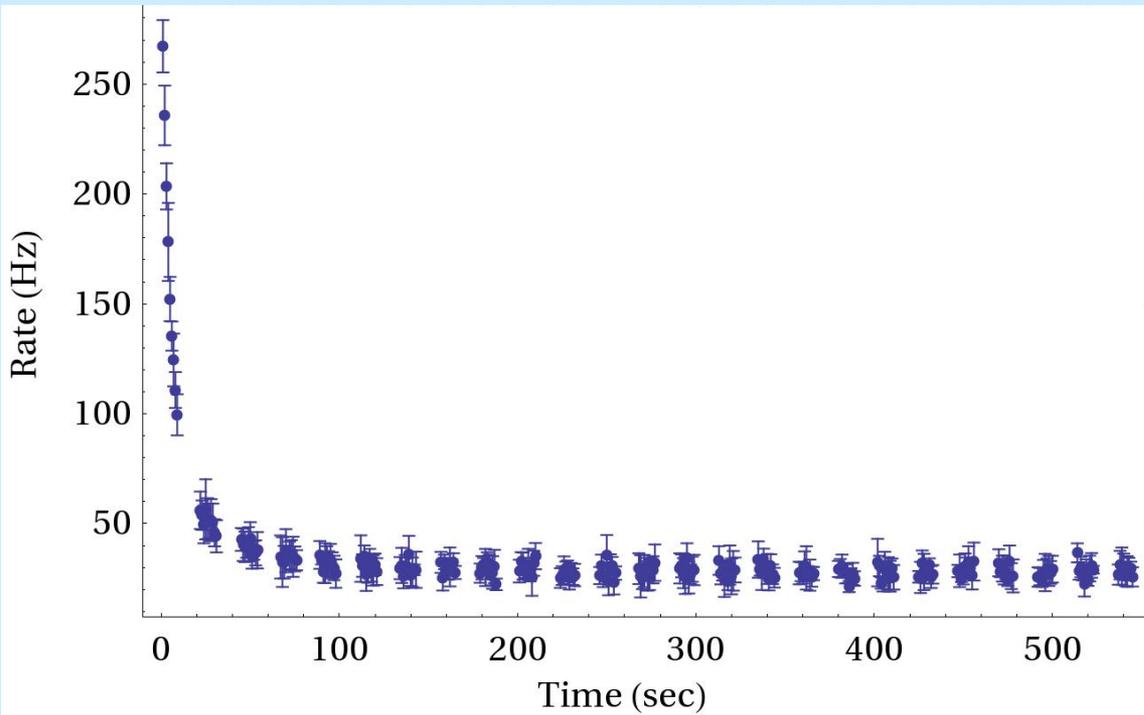
Employ the “dish rack” to effectively have 5m, 95cm, 5cm magnetic field regions -a bit of cleverness similar to the plunger idea to be initially sensitive to a wider range of chameleon masses.





Two unexpected systematics

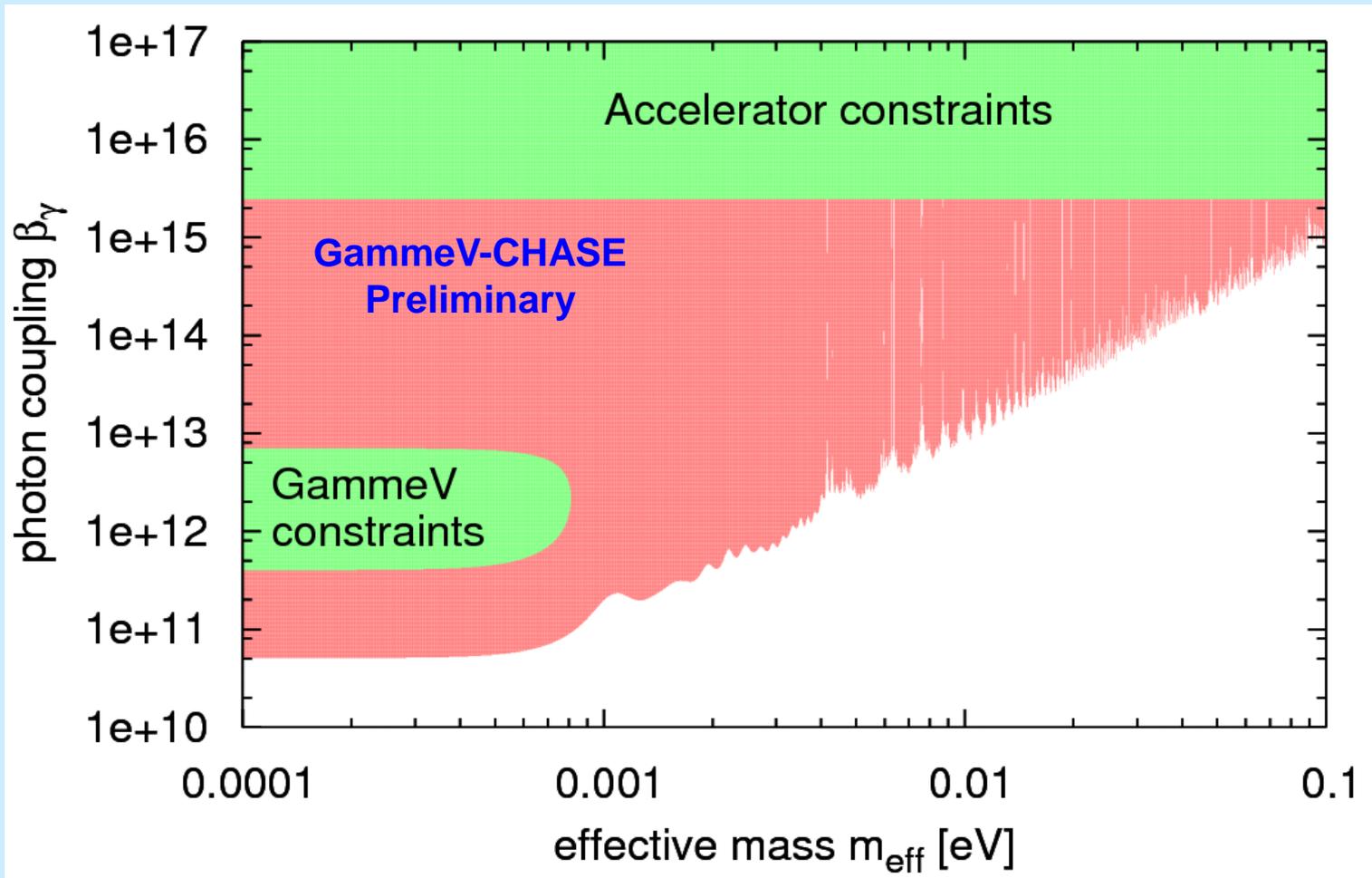
- About 1-2 Hz of photons from the ion pump
- An orange glow ... a background (no B field dependence)



Afterglow rate has a strong temperature dependence

- Current hypothesis is that material freezes to internal windows or defects in the window phosphoresce - investigations continue

GammeV CHASE Preliminary results

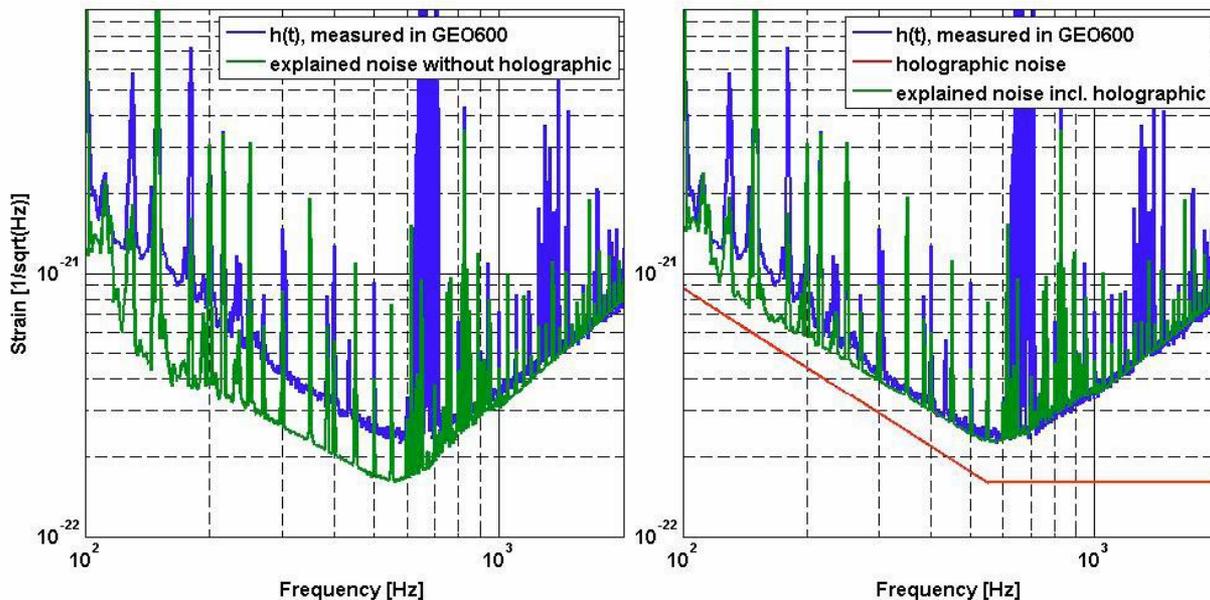


Preliminary results agree with design expectations:

A. Upadhye, J. Steffen, A. Weltman, Phys. Rev. D **81**, 015013 (2010)

And now for something completely different ...

- Plans for R&D towards high finesse long optical cavity overlap with a theoretical idea from Craig Hogan ...
 - **Holographic noise:** a new jitter of space time due to Planck scale effects
- A possible hint from GEO600 Gravity wave experiment

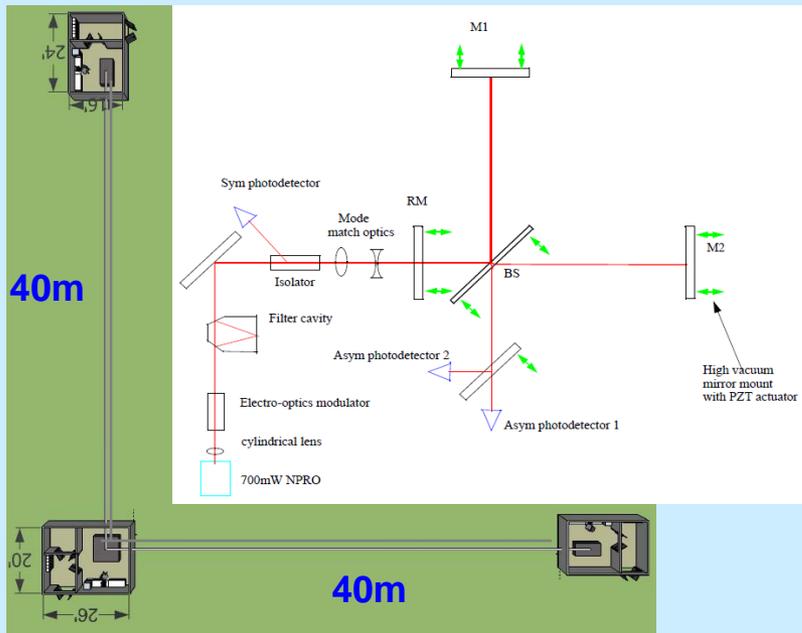


At $f > 600$ Hz, a 0-parameter prediction invoking the expected holographic noise, explains nearly all of the “mystery noise.”

A detailed analysis is in progress.

A Quantum Holometer

- A proposed experiment is to build two interferometers with $\sim 40\text{m}$ arms to search for the correlated holographic noise and to observe its predictable decorrelation when the geometry of the interferometer is re-arranged.



$$l_P = \sqrt{\hbar G_N / c^3} = 1.616 \times 10^{-33} \text{cm}$$

$$\Delta x_{\perp}^2 > l_P L$$

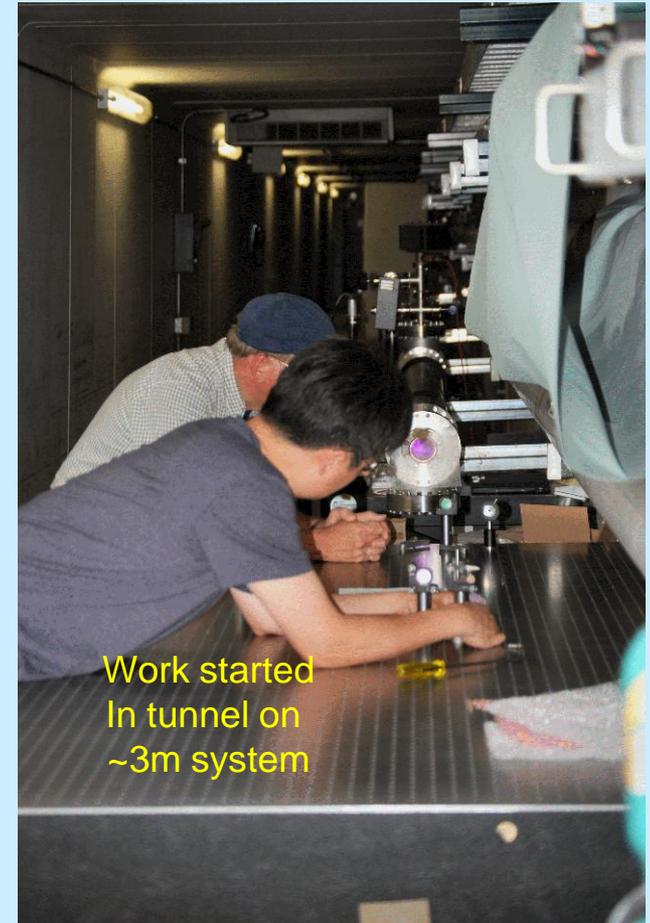
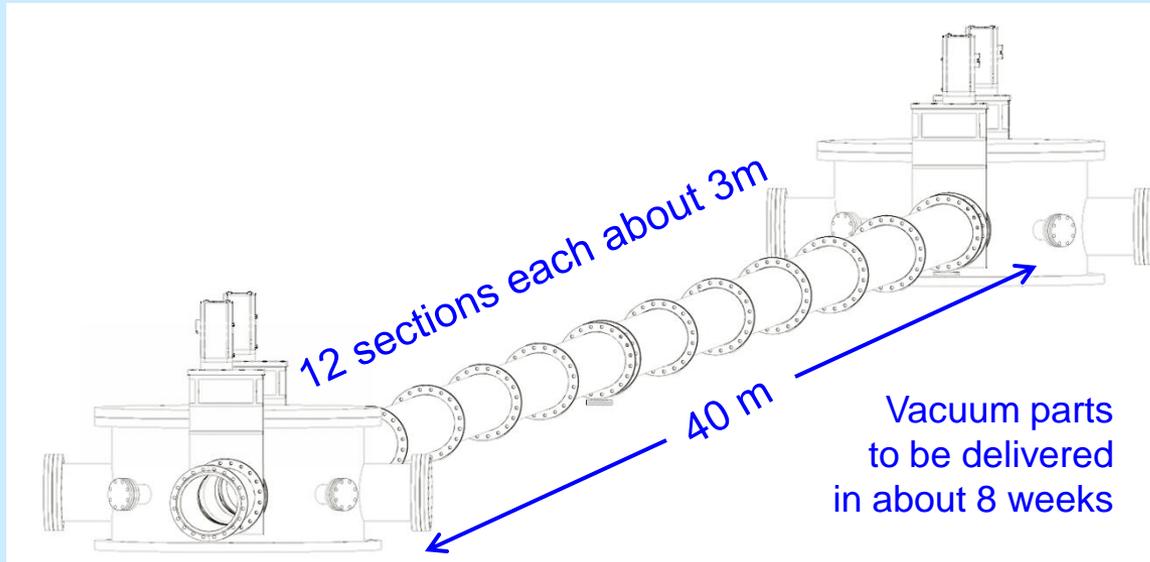
- C. Hogan, "Holographic Noise in Interferometers"
<http://arxiv.org/abs/0905.4803>
- C. Hogan, "Interferometers as Holographic Clocks"
<http://arxiv.org/abs/1002.4480>

- A new team including LIGO experts at MIT and Caltech are collaborating. Initial reviews at FNAL are positive.

40m optical cavity R&D

- Overlaps with holometer proposal and resonant axion-photon regeneration R&D

Holometer proposal presented Nov 2009 to Fermilab's Physics Advisory Committee
Positive response. Waiting for grants or other funding to materialize.



Conclusions

- Fermilab has published results on axion-like particles and chameleons. New results on chameleons are presented.
- Next experiments are much more ambitious and we are starting to get experience with optical cavities and interferometers. New lab support and new collaborators.
- New ideas are frequent and might lead to experiments not yet thought of such as holographic noise.
- GammeV has trained two postdocs (now Wilson fellows) and the third postdoc, Jason Steffen, lead the GammeV-CHASE experiment.