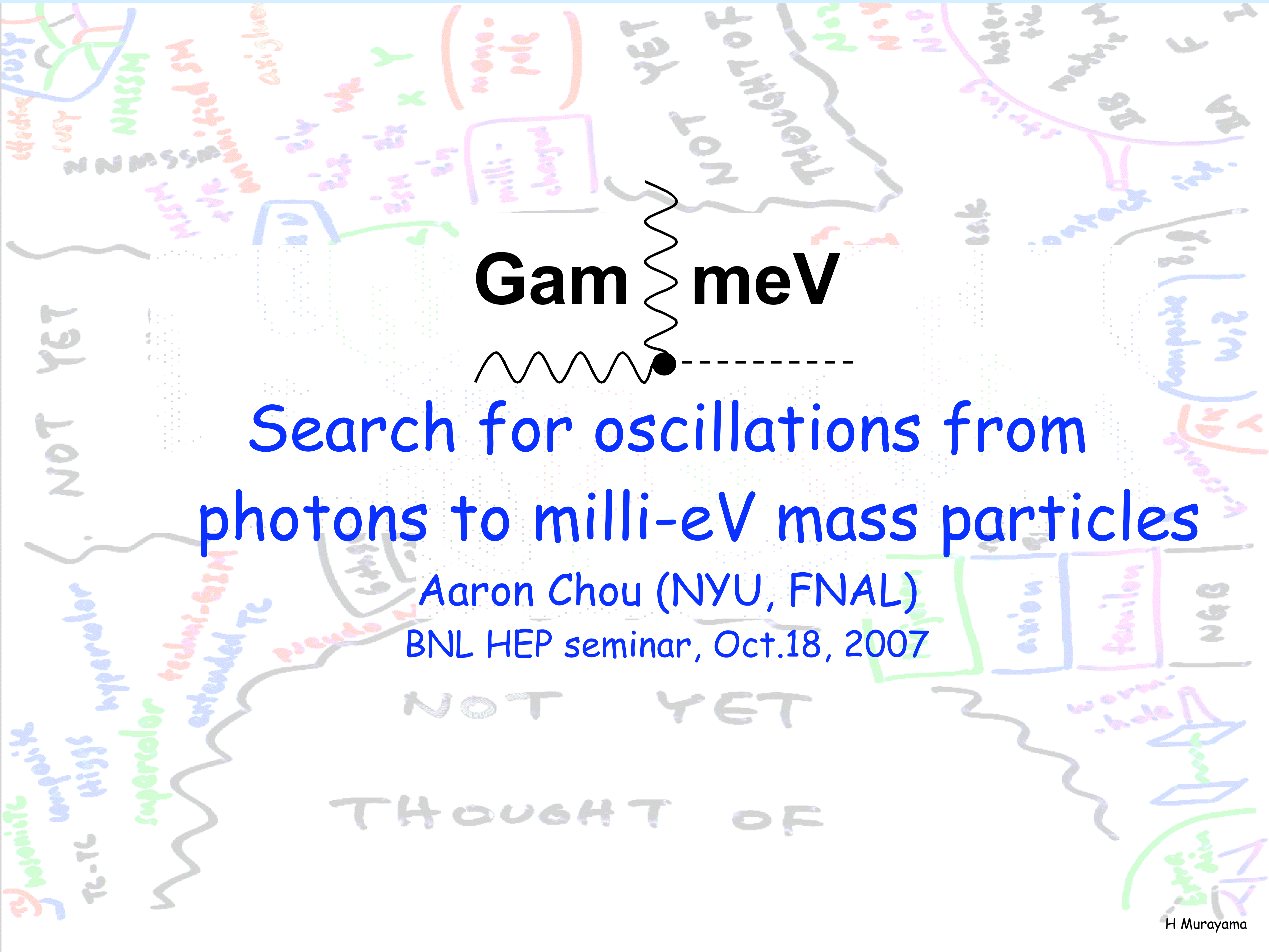


GammeV

Search for oscillations from photons to milli-eV mass particles

Aaron Chou (NYU, FNAL)

BNL HEP seminar, Oct.18, 2007

milli-eV Mass Scale

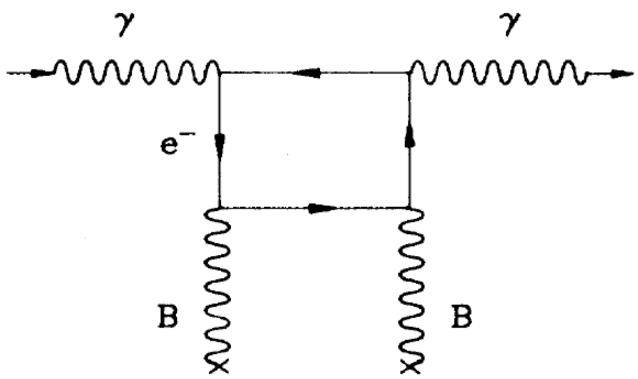
- milli-eV (10^{-3}) eV mass scale arises in various areas in modern particle physics.
  - Dark Energy density
    - $\Lambda^4 = 7 \times 10^{-30}$ g/cm^3 ~ $(2\times10^{-3}\ \mathrm{eV})^4$
  - Neutrinos
    - $(\Delta m_{21})^2 = (9\times10^{-3}\ \mathrm{eV})^2$
    - $(\Delta m_{32})^2 = (50\times10^{-3}\ \mathrm{eV})^2$
  - See-saw with the TeV scale:
    - meV ~ $\mathrm{TeV}^2/M_{planck}$
  - Dark Matter Candidates
    - Certain SUSY sparticles (low mass gravitino)
    - Axions and axion-like particles

Energy frontier
Neutrinos
Astrophysics
all in one!

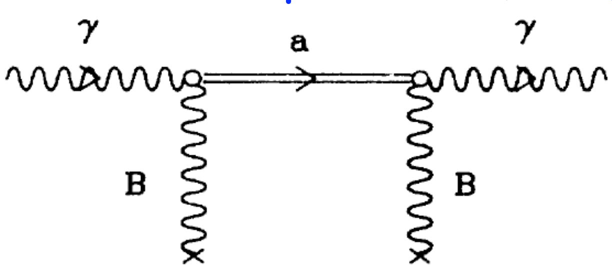
Has the meV scale been seen in photon-photon scattering?

- We expect condensed matter systems to exhibit non-trivial optical properties
  - Birefringence: index of refraction depends on polarization
  - Dichroism: preferential absorption of one polarization
  - Non-linear photon-photon processes give useful effects such as 2nd harmonic generation
- Does the vacuum have similar properties???
  - Non-linear QED processes are suppressed by $(E/m_e)^4$, and not presently observable
  - High flux beam and low background = Opportunity to search for new physics!

Delbruck scattering



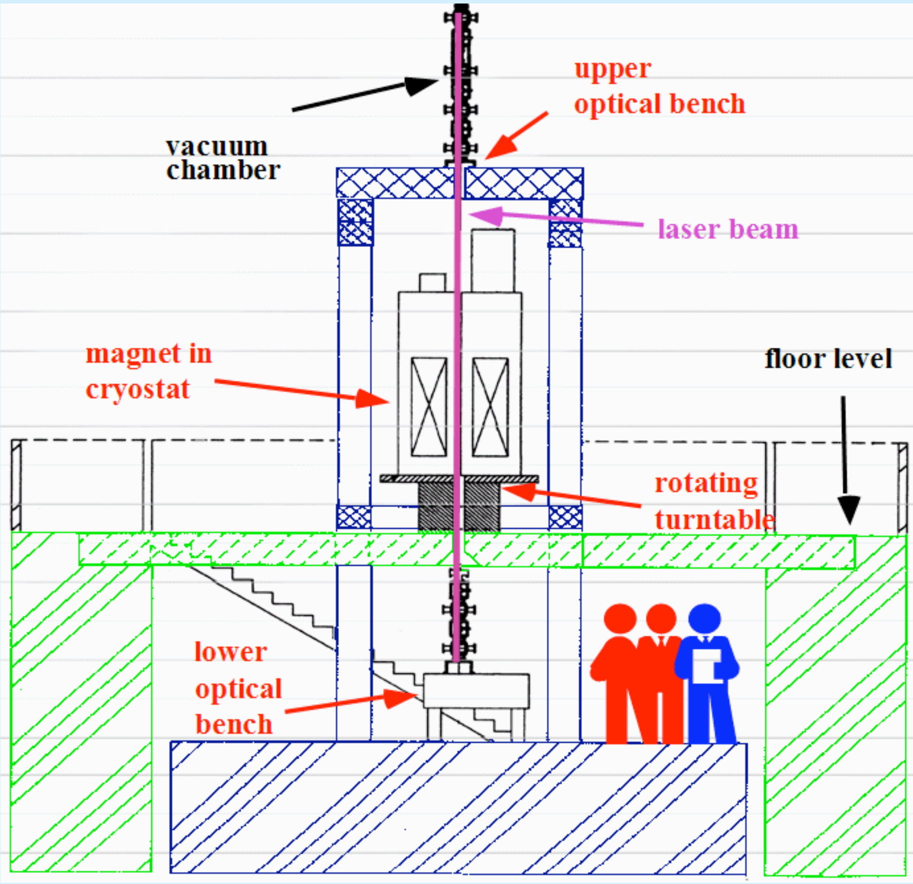
Axion-like particle (ALP)

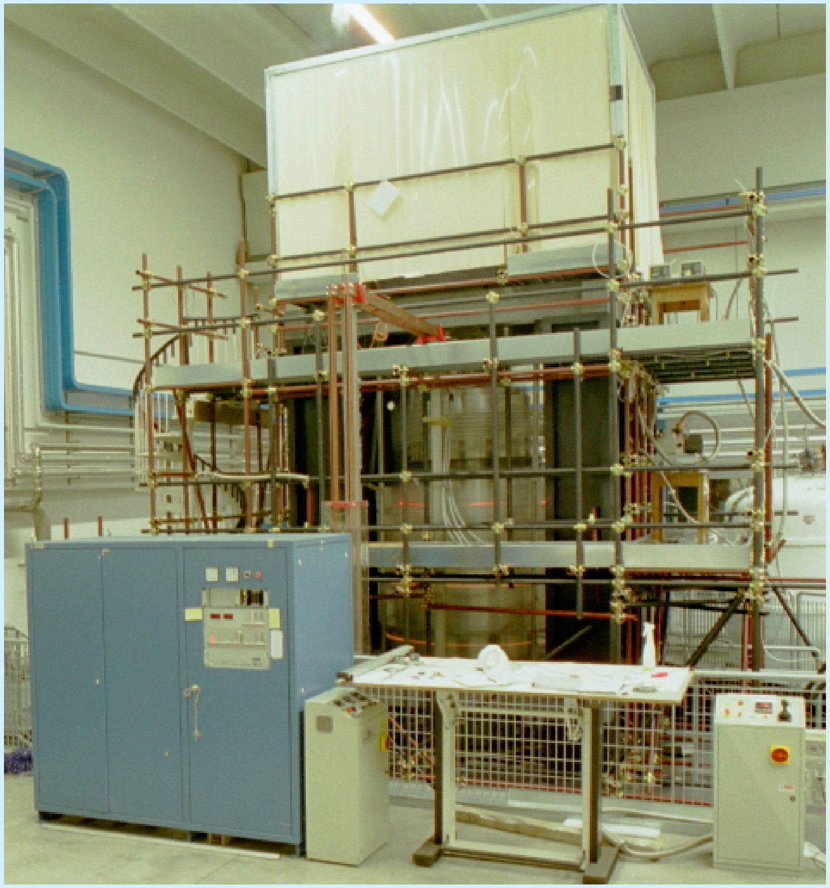


PVLAS Experiment

- Shoot a linearly polarized laser beam (1064nm or 532 nm) into a magnetic field and look for birefringence (generated ellipticity) and dichroism (rotated polarization)

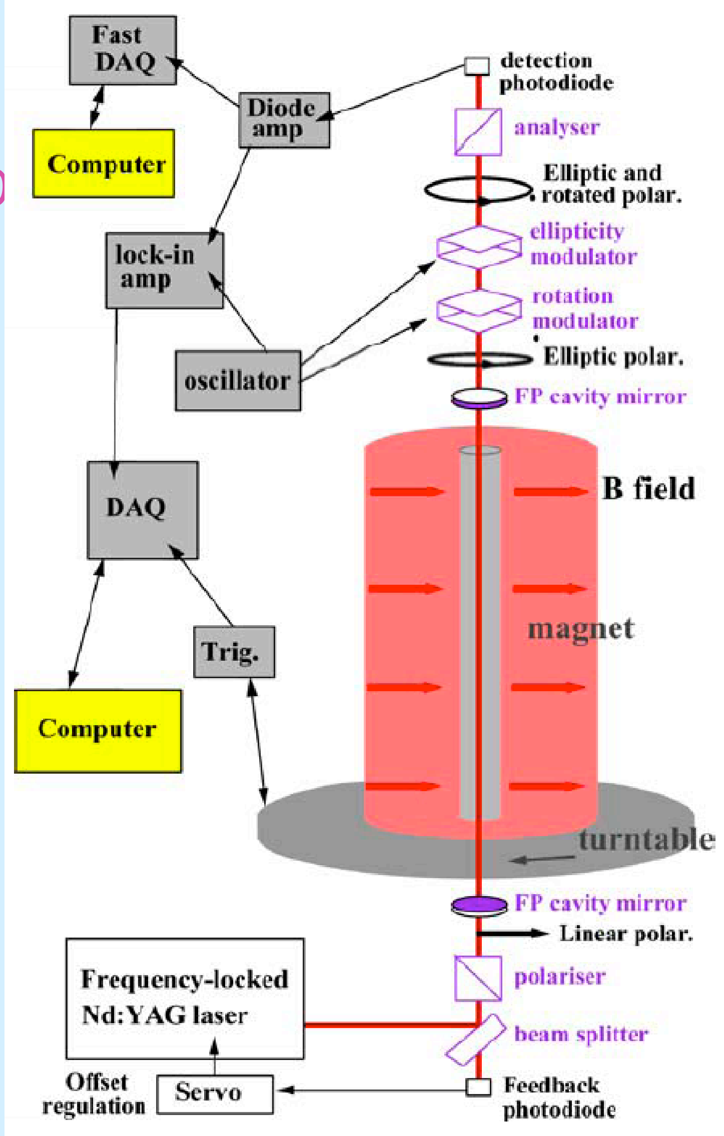
INFN, Legnaro





PVLAS Experiment

- Rotating SC magnet (~0.5 Hz)
- Modulators for heterodyne detection with ~500 Hz carrier frequency
- Measure rotation/ellipticity using crossed polarizers with ~10^{-8} radian resolution.
  - Clever measurement of relative attenuation, not absolute attenuation!
- Optical cavity to increase laser path length in the external B_{ext} field
  - Total rotation/ellipticity signal = sum of ~42000 single-pass signals
  - Single pass resolution = 10^{-13} radians.
- Expect signals in 2nd mixing harmonic only when B_{ext} field is aligned with either E or B of the γ

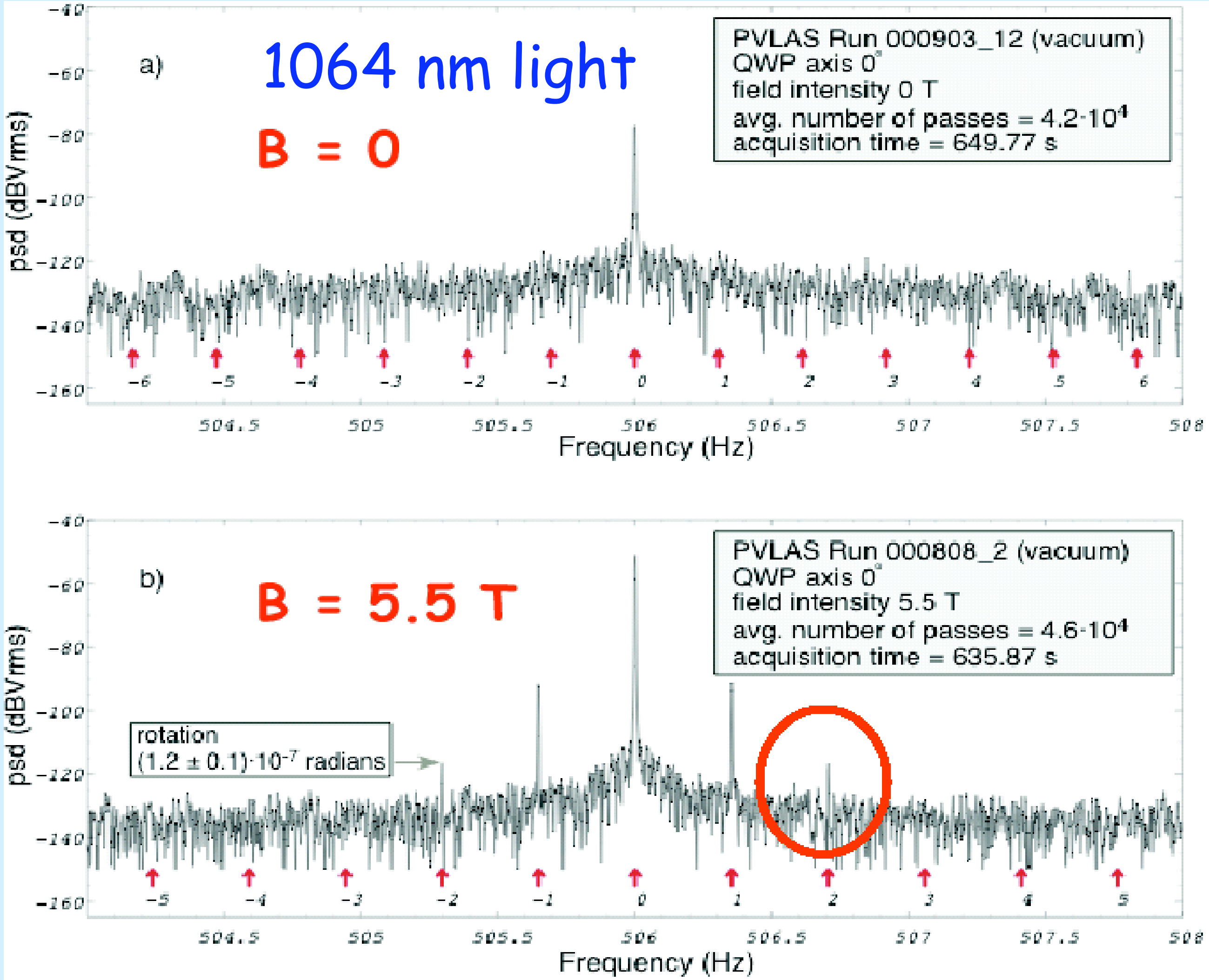


PVLAS Rotation Power Spectrum

Amplitude of 2nd harmonic = total rotation signal after ~42000 passes in the 1 meter cavity

Hypothesis: photons of one polarization convert to weakly-interacting particles which escape through the cavity mirrors.

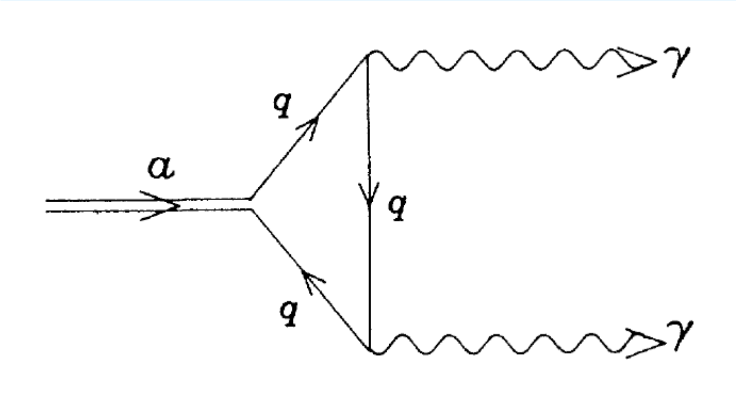
--> Disappearance experiment



PRL 96, 110406, (2006)

Axion-like particles (ALPs)

Two-photon coupling induced (for example) by a heavy fermion of mass M.



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

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

General paradigm of particles from the "dark sector" coupling to particles from the visible sector only via heavily suppressed interactions.

Other examples: Axions/dilatons/radions from string theory, Large extra dimensions, Randall-Sundrum theories….

GamameV Coupled wave equations

In the presence of a background magnetic field B_{ext}:

$$\begin{bmatrix} \omega^2+\partial_z^2 & 0 & 0 \\ 0 & \omega^2+\partial_z^2 & -iB_{\rm ext}\omega/M \\ 0 & +iB_{\rm ext}\omega/M & \omega^2+\partial_z^2-m^2 \end{bmatrix} \begin{pmatrix} A_o \\ A_p \\ a \end{pmatrix} = 0$$

Raffelt,Stodolsky

Off-diagonal terms in Hamiltonian couple the scalar field to one of the photon polarization components.

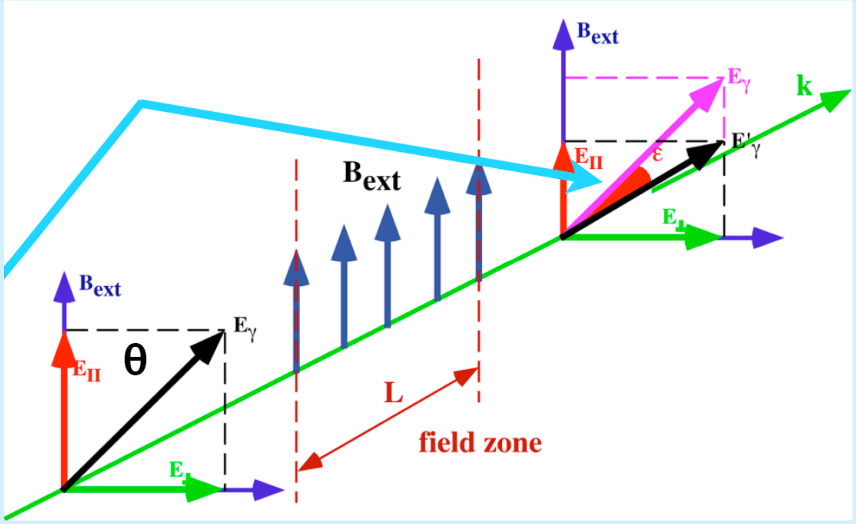
$$P_{\gamma\to\phi} = \frac{4B^2\omega^2}{M^2(\Delta m^2)^2}\sin^2\left(\frac{\Delta m^2 L}{4\omega}\right)$$

$$\Delta m^2 = m_\phi^2 - m_\gamma^2$$

PVLAS:
$m_\phi=10^{-3}$ eV
M~5 x 10^5 GeV

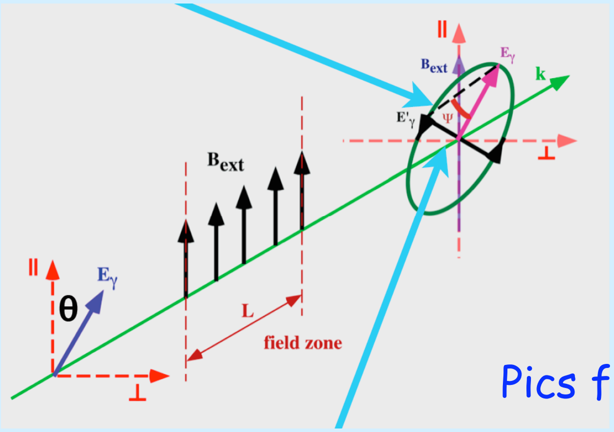
Rotation/Ellipticity

Polarization rotation due to on-shell particles escaping cavity.



$$\epsilon = \frac{B^2\omega^2}{M^2 m_\phi^4}\sin^2\left(\frac{m_\phi^2 L}{4\omega}\right)$$

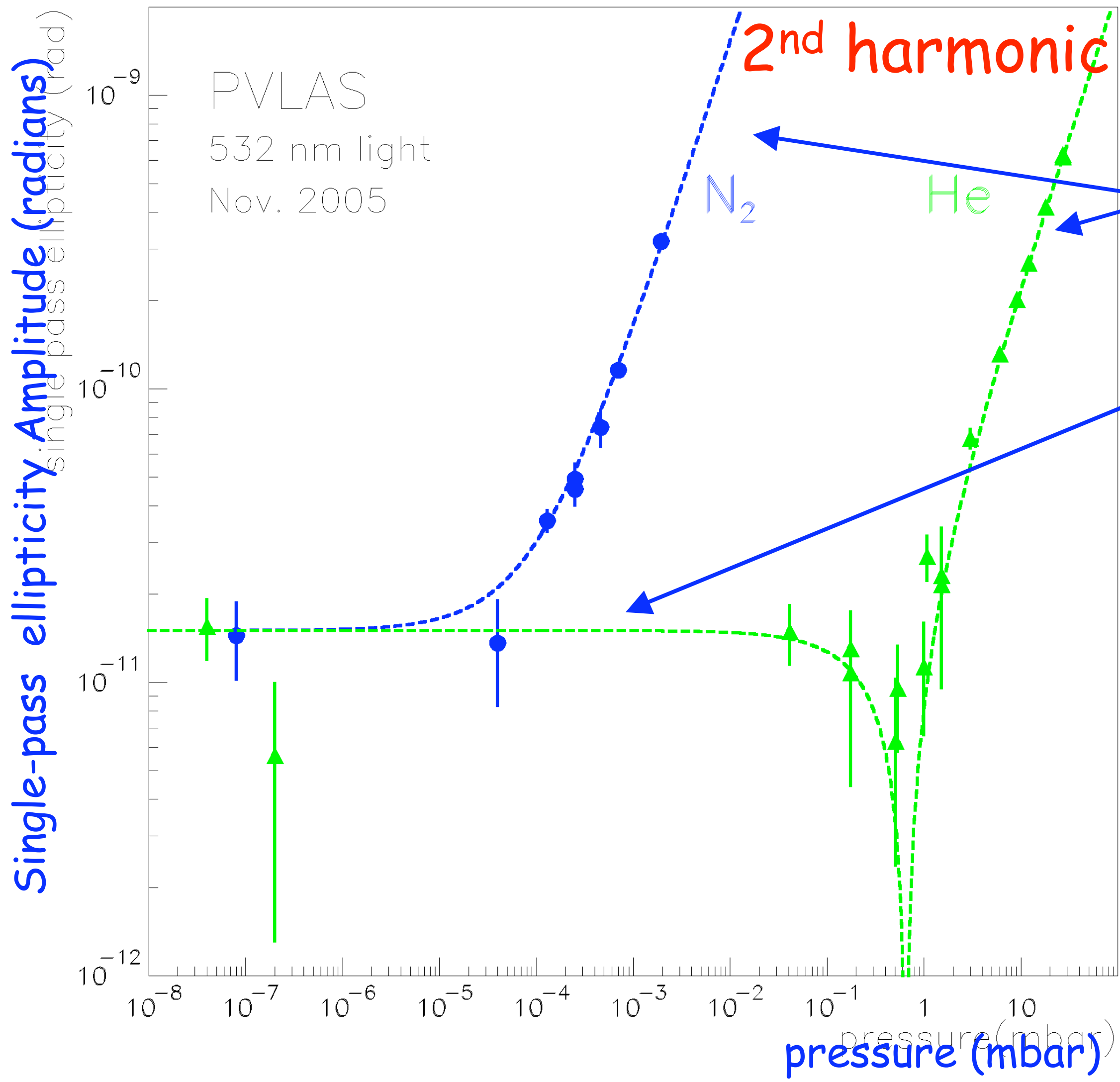
Ellipticity due to creation of virtual particles-->increased phase velocity



$$\psi = \frac{B^2\omega^2}{2M^2 m_\phi^4}\left(\frac{m_\phi^2 L}{2\omega} - \sin\left(\frac{m_\phi^2 L}{2\omega}\right)\right)$$

Pics from G. Cantatore

Ellipticity vs Pressure

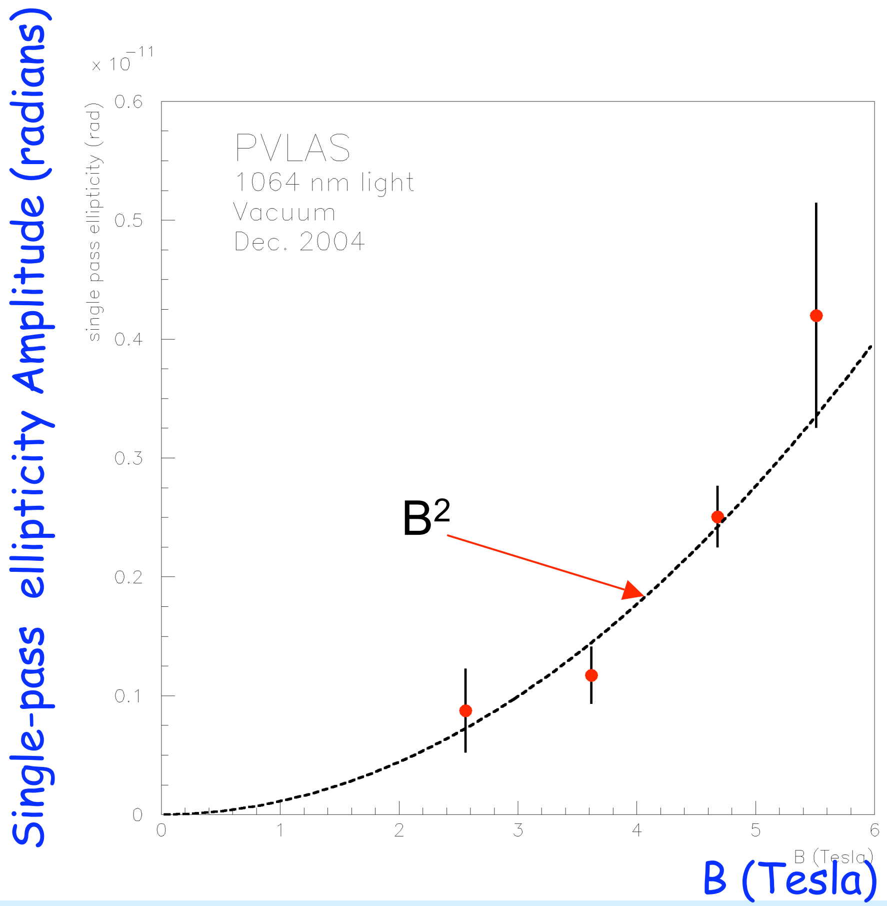


Cotton-Mouton effect vs gas pressure

Non-zero asymptotic 2nd harmonic amplitude at zero pressure indicates birefringence of the vacuum. Phase implies even parity coupling.

Conferences only

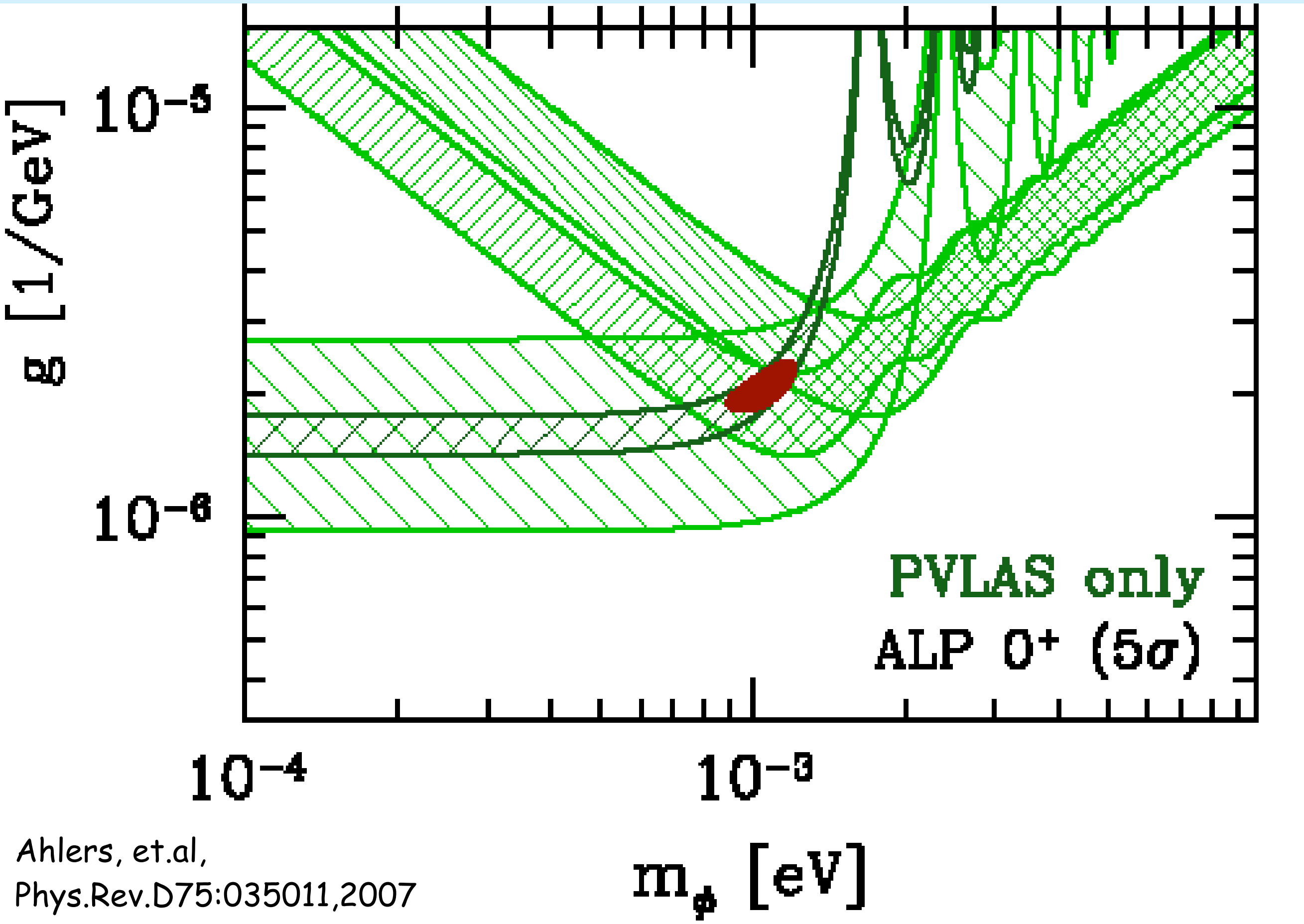
PVLAS Vacuum Ellipticity vs B field



$$\psi = \frac{B^2\omega^2}{2M^2 m_\phi^4}\left(\frac{m_\phi^2 L}{2\omega} - \sin\left(\frac{m_\phi^2 L}{2\omega}\right)\right)$$

ICHEP2006

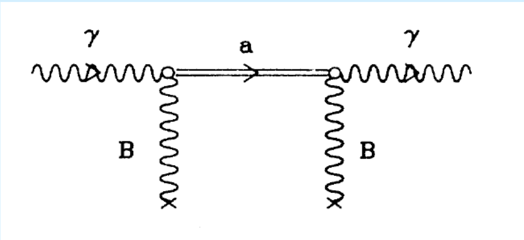
PVLAS ALP Interpretation



Ahlers, et.al, Phys.Rev.D75:035011,2007

4 measurements give a consistent picture of a particle with mass 1.2 meV and coupling $g \sim 2 \times 10^{-6}$ GeV^{-1}

Need a good vacuum to see low mass



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

$$\Delta m^2 = m_\phi^2 - m_\gamma^2$$

$$m_\gamma^2 = -2\omega^2(n-1)$$

Reduced photon phase velocity modeled as imaginary photon mass.

For maximum sensitivity, need a good vacuum to maximize v_γ.

Otherwise $v_\gamma < c$ increases the phase velocity mismatch with $v_\phi > c$ and the resulting oscillation minimum might coincide with the baseline.

Pressure dependence of PVLAS

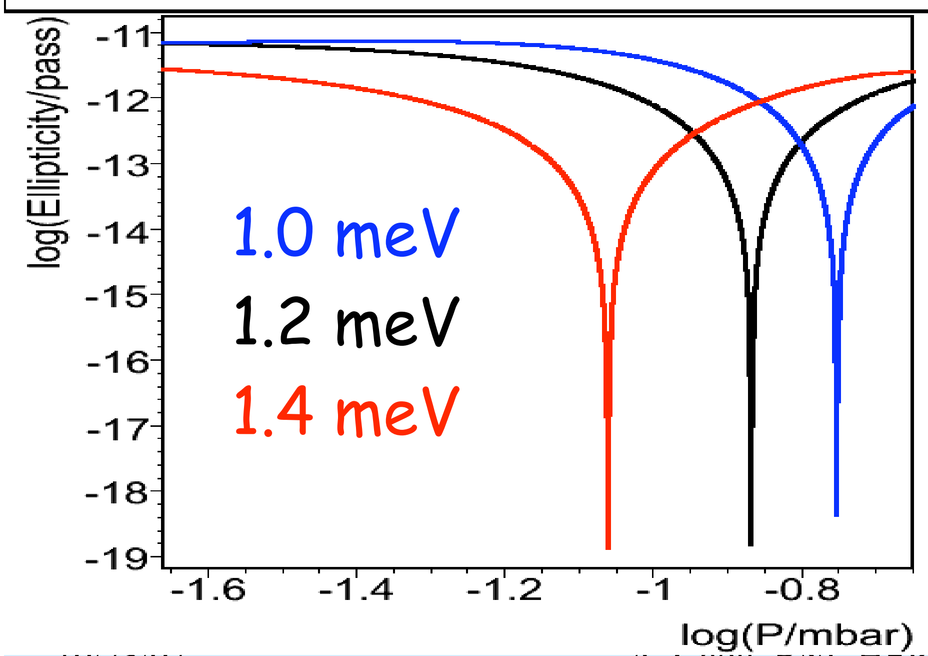
$$\Delta m^2 = m_\phi^2 - m_\gamma^2 = m_\phi^2 + 2\omega(n-1)$$

$$n - 1 \propto \rho_{gas} \propto P_{gas} / T_{gas}$$

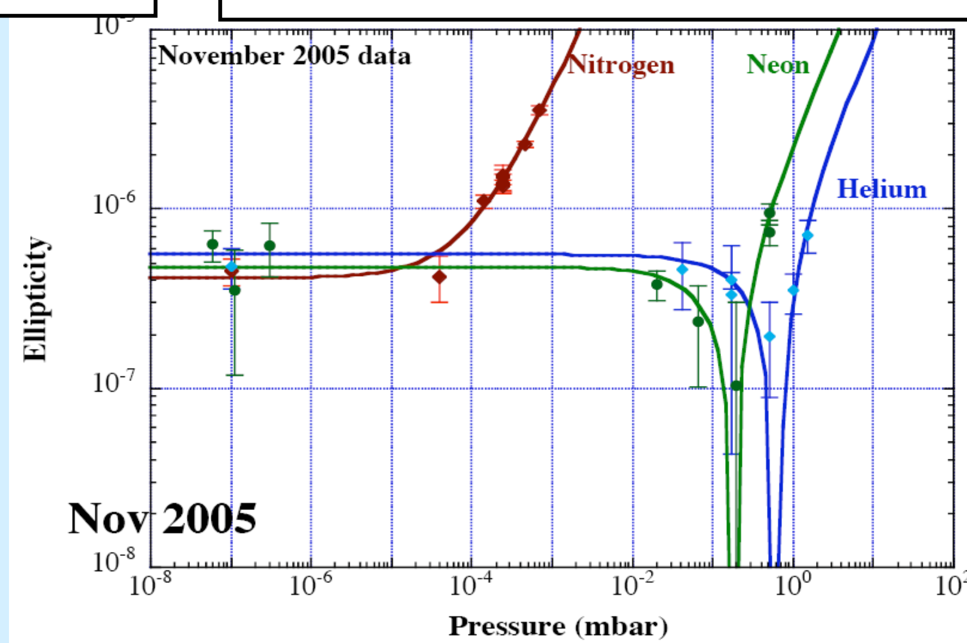
$$P_{\gamma\rightarrow\phi} \propto (\Delta m^2)^{-2} \propto (T_{gas} / P_{gas})^2$$

for $m^2_\gamma > m^2_\phi$

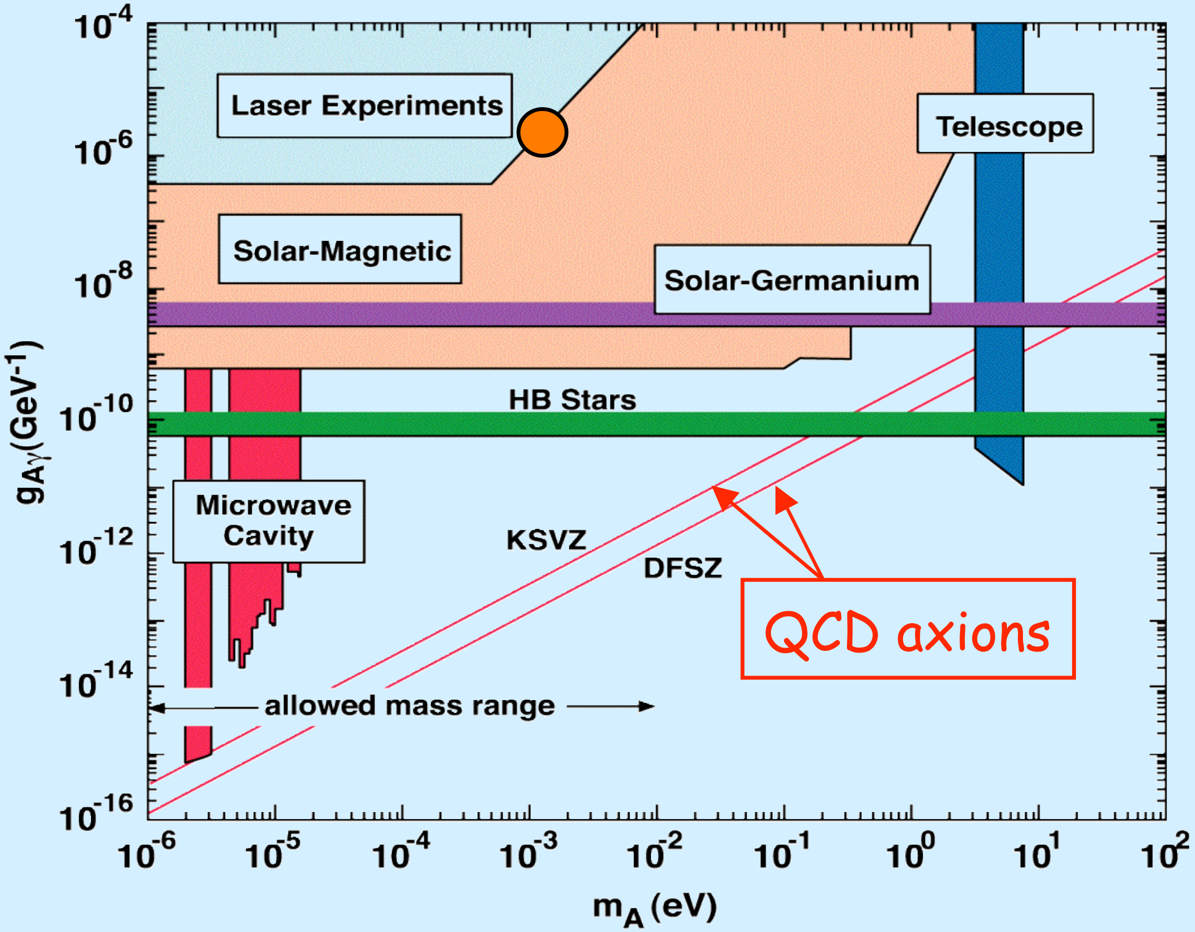
Aaron's prediction for neon at 4.7K



PVLAS results ICHEP06



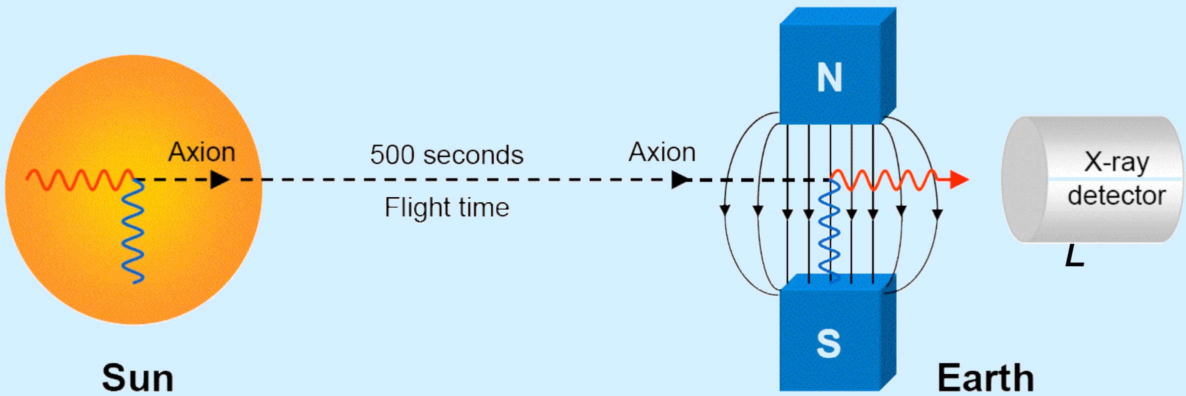
Star cooling constraint

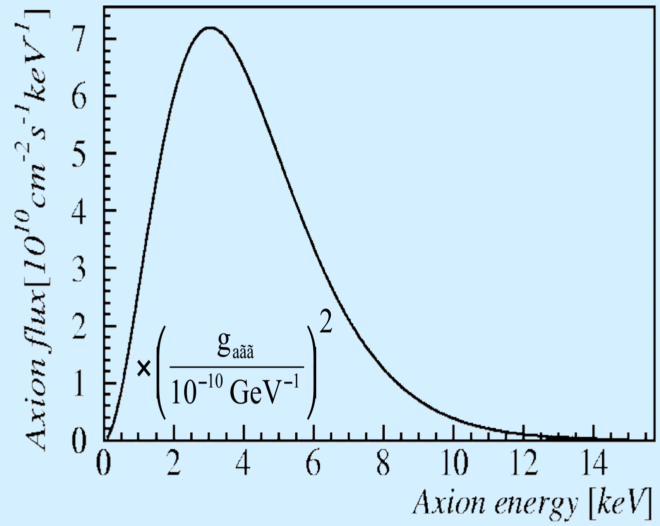


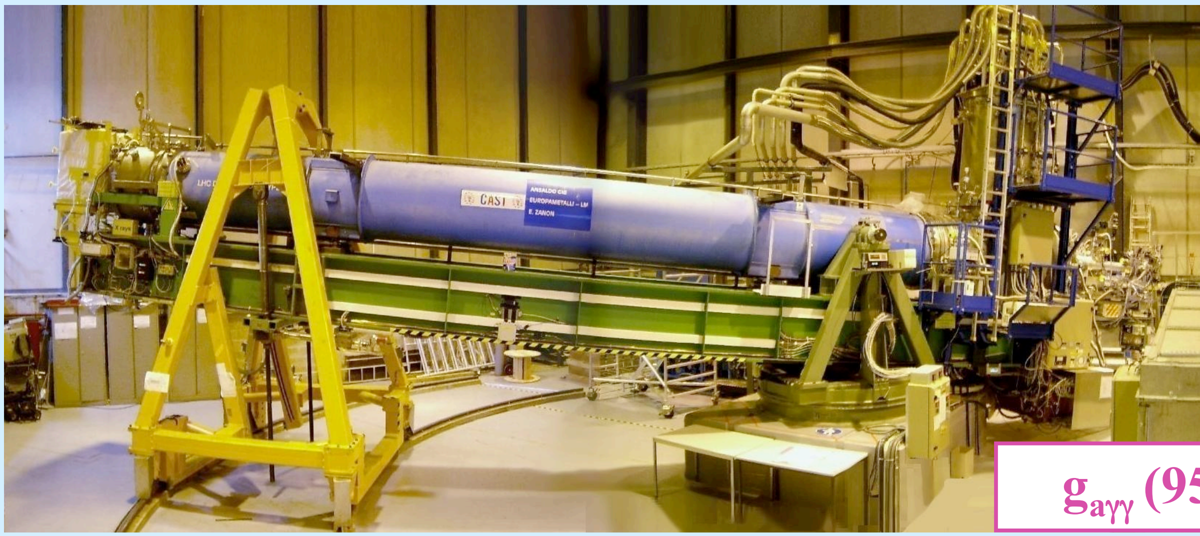
Couplings this strong for low mass particles ($m < T_{star}$) are excluded by star cooling! The sun lives for only 1000 years…

CAST Experiment excludes PVLAS ALPS

- CERN Axion Solar Telescope







Point LHC dipole toward the sun.

Detect X-rays from axion reconversion.

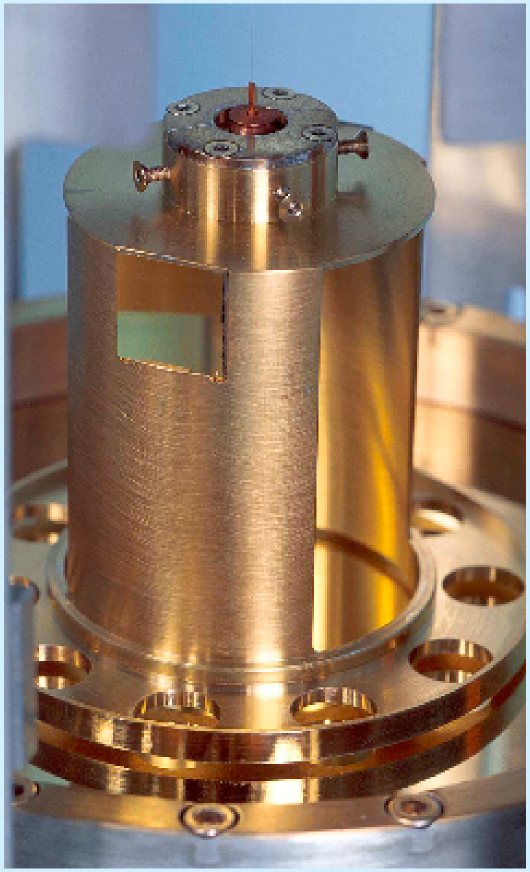
$g_{a\gamma\gamma}$ (95% C.L.) < 1.16×10^{-10} GeV^{-1}

GammeV Some ideas to evade astrophysical bounds

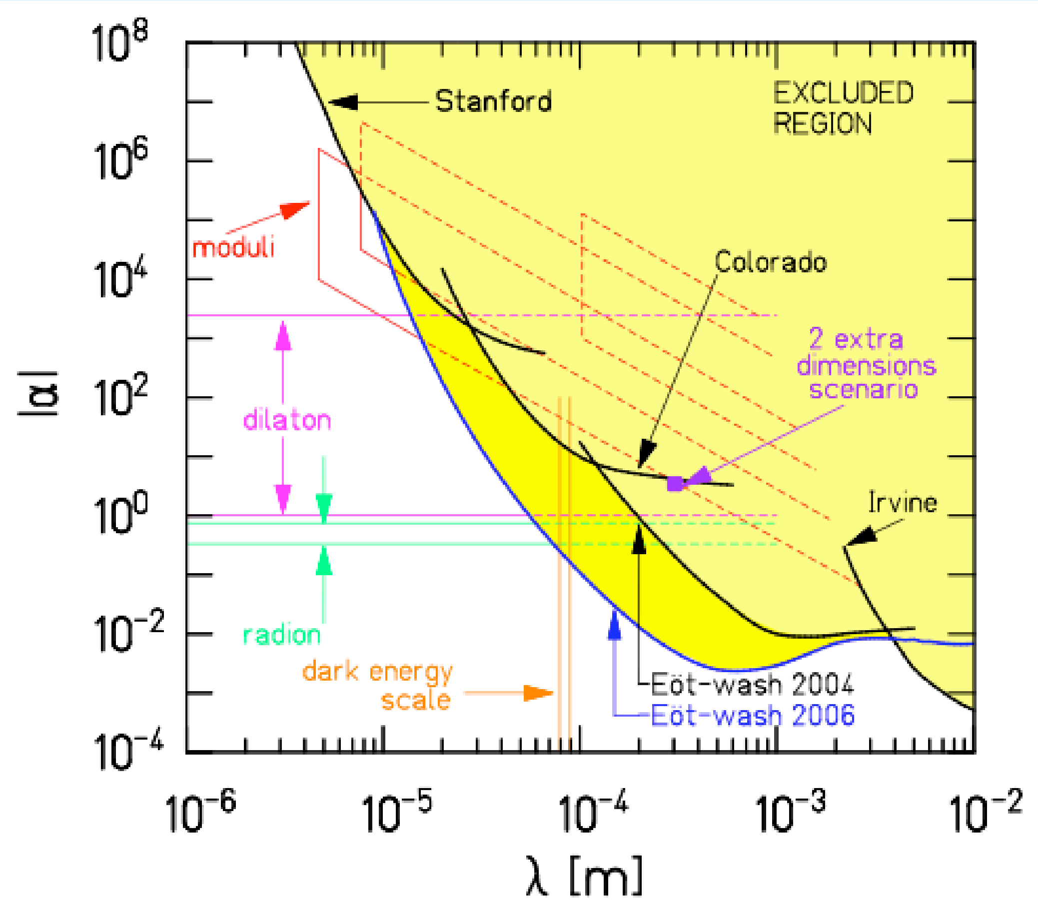
- Masso & Redondo: ALPs are composite particles made of microcharged fermions. Microcharges arise naturally via coupling to a "paraphoton" from a second U(1) gauge symmetry. The fermions get micro-electric charges under the EM U(1) from small mixings between the paraphoton and the EM photon. Not a pretty theory.
- Antoniadis: ALPs are really vector particles with very small coupling to photons. The mixing is a kinetic mixing rather than a mass mixing. (Ad hoc Chern-Simons term not gauge invariant? C. Hill).
- Ringwald et.al: The PVLAS signal is not ALPS but rather just pair production of micro-charged fermions. Excluded by cosmology (Mohapatra/Nussinov).
- Brax et.al: scalar particles are chameleons and have strong matter effects. Hence, solar production is kinematically suppressed. But scaling with density is not strong enough? (AC,A. Weltman,A.Upadhye).

GammeV Tests of gravitational ISL

New light scalars would be expected to mediate new long range forces



Biggest disappointment of 2006: Eot-Wash sees no deviation from ISL at the meV scale.



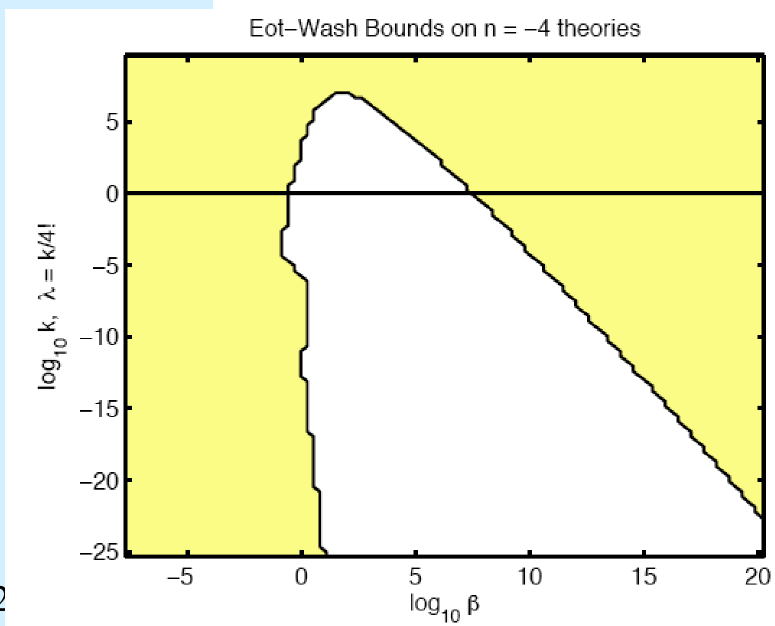
PVLAS scalar coupling excluded by 11 orders of magnitude (Dupays et.al)

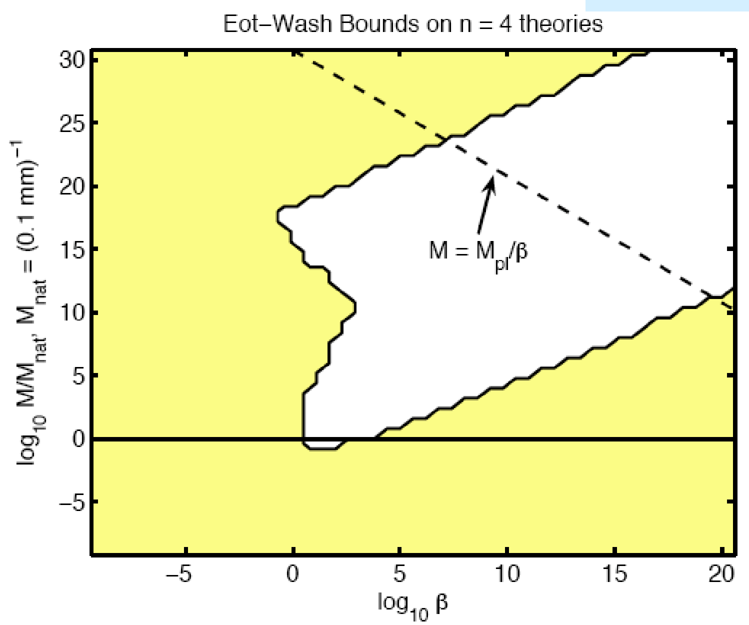
GammeV

Evading ISL constraints

- Low mass particle is a pseudoscalar --> Spin dependent force ~ $1/R^3$
- Low mass particle has strong matter effects (Khoury/Weltman chameleons)
  - Effective mass in material >> vacuum mass
  - Meissner-like shielding --> only a thin shell of material near the surface of the pendula interact so torque is much smaller
  - Electrostatic shielding film between the two pendula also block the exchange of chameleon particles

$$V(\phi) = \lambda M^4 (M/\phi)^n + B(\beta\phi/M_{pl})\rho$$





Mota, Shaw, 2006

Summary of PVLAS ALPs

Positives for a new particle interpretation

-Effect seen in both ellipticity and rotation at 532 and 1064nm

-Cotton Mouton effect is observed as expected

-B field, pressure dependence as expected

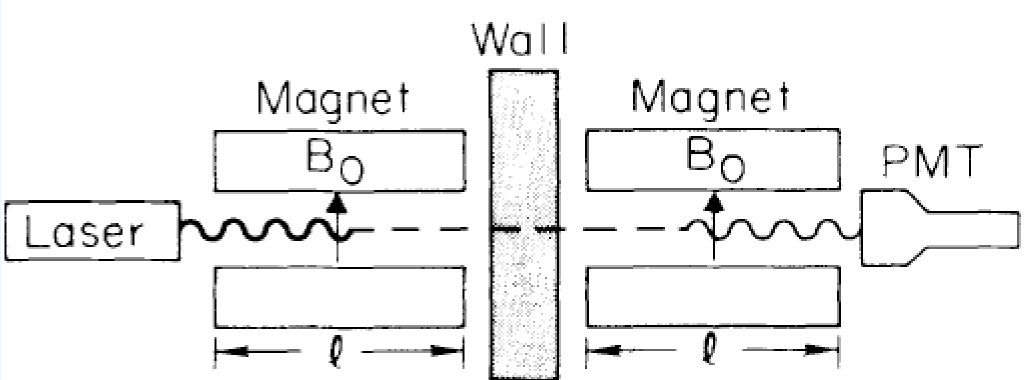
-Copious theoretical ideas to evade astrophysical and other bounds

Concerns

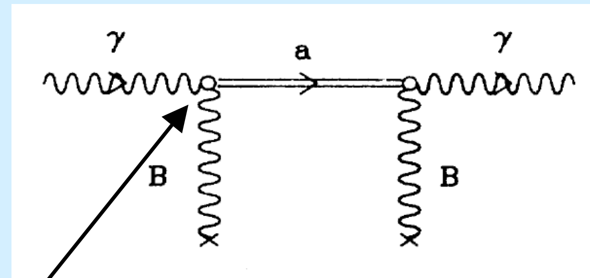
--**After rebuilding the apparatus, the PVLAS signal has disappeared for reasons unknown. New preprint (hep-ex/0706.3419), concludes there is likely an instrumental artifact in the original measurement but cannot say what. PVLAS will continue testing.**

GammeV motivation is to test the axion-like particle interpretation of the PVLAS anomaly in a direct manner

Shining Light Through a Wall



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



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

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

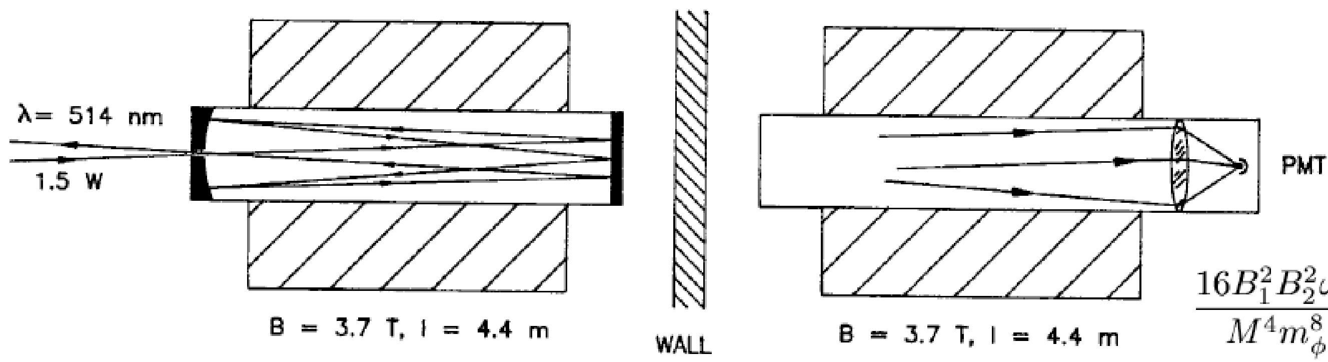
Assuming 5T magnet, the PVLAS “signal”, and 532nm laser light

$$P_{regen}^{GammeV} = (3.8\times10^{-21})\times\frac{(B_1/5\ \mathrm{T})^2(B_2/5\ \mathrm{T})^2(\omega/2.33\ \mathrm{eV})^4}{(M/4\times10^5\ \mathrm{GeV})^4(m_\phi/1.2\times10^{-3}\ \mathrm{eV})^8}$$
$$\times\sin^2\left(\frac{\pi}{2}\frac{(m_\phi/1.2\times10^{-3}\ \mathrm{eV})^2(L_1/2.5\ \mathrm{m})}{(\omega/2.33\ \mathrm{eV})}\right)\sin^2\left(\frac{\pi}{2}\frac{(m_\phi/1.2\times10^{-3}\ \mathrm{eV})^2(L_2/2.5\ \mathrm{m})}{(\omega/2.33\ \mathrm{eV})}\right)$$

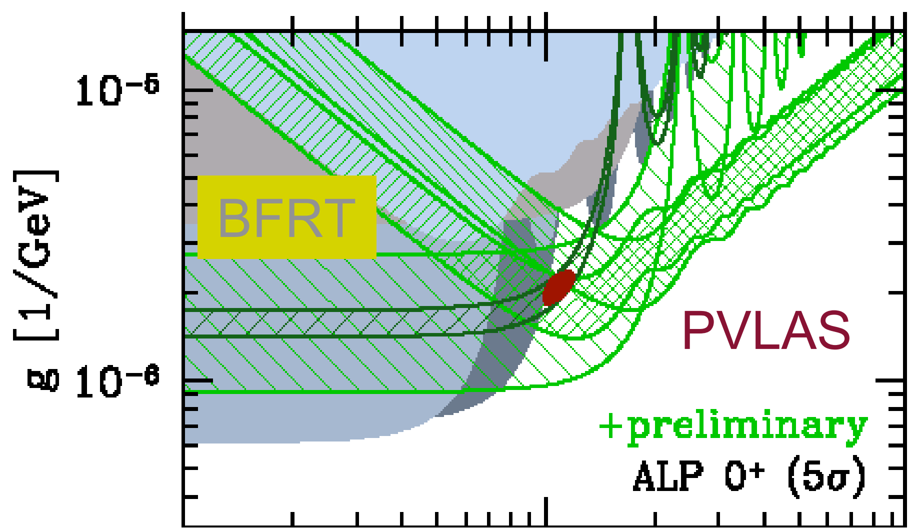
GammeV

BFRT: The first photon regeneration expt.

- Brookhaven, Fermilab, Rochester, Trieste (1992)



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



BFRT was not sensitive in the PVLAS region because the 4.4 m baseline given by their fixed magnet lengths gives an oscillation minimum at ~1 milli-eV for green light

GammeV

Search for axion-like particles using a variable baseline photon regeneration technique

A. S. Chou[1,2], W. Wester[1], A. Baumbaugh[1], H. R. Gustafson[3], Y. Irizarry-Valle[1], P. O. Mazur[1], J. H. Steffen[1], R. Tomlin[1], X. Yang[1], and J. Yoo[1]
[1]*Fermi National Accelerator Laboratory, PO Box 500, Batavia, IL 60510*
[2]*Center for Cosmology and Particle Physics, New York University, 4 Washington Place, New York, NY 10003*
[3]*Department of Physics, University of Michigan, 450 Church St, Ann Arbor, MI 48109*
(Dated: October 22, 2007)

Ten person team including a summer student, 3 postdocs, 2 accelerator / laser experts, 4 experimentalists
PLUS technical support at FNAL

Nov 2006 : Initial discussion and design (Aaron Chou, William Wester)
Apr 2007 : Review and approval from Fermilab ($30K budget!)
May 2007 : Acquire and machine parts
Jun 2007 : Assemble parts, test electronics and PMT calibration
Jul 2007 : First data but magnet and laser problems
Aug 2007 : Start data taking in earnest
Sep 2007 : Complete data taking and analysis

GammeV

Bargain. Wester (*left*) and Chou say their experiment offers high potential payoff at low cost.

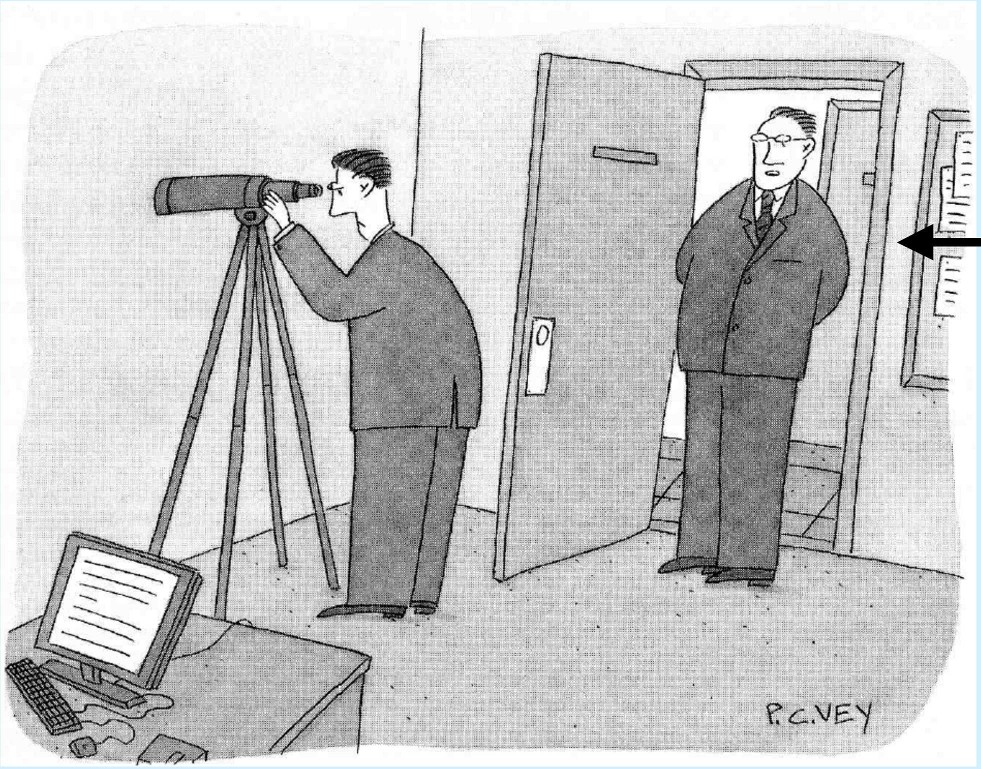
PARTICLE PHYSICS

A Spare Magnet, a Borrowed Laser, and One Quick Shot at Glory

Using equipment they have on hand, a small band of physicists hopes to confirm the existence of a new particle—by shining a laser through a wall

GammeV

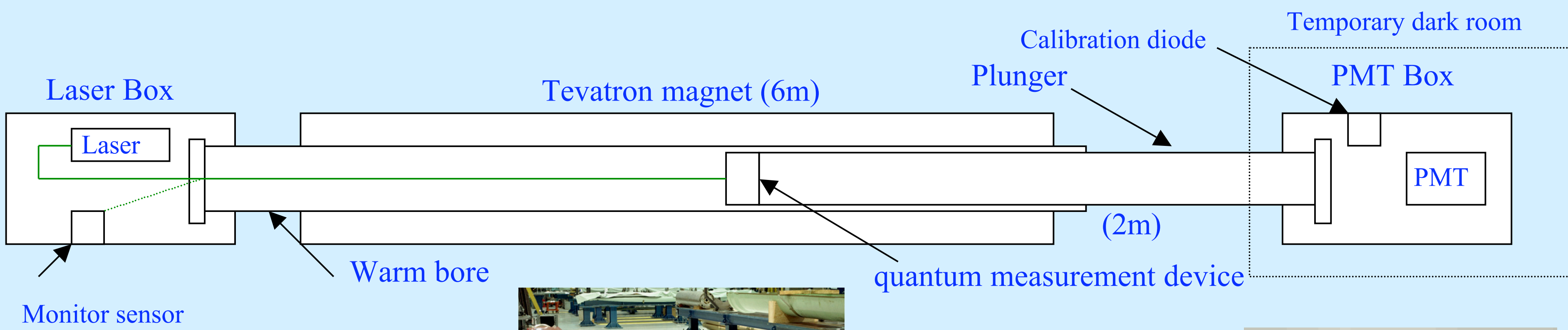
All of us had day jobs too….

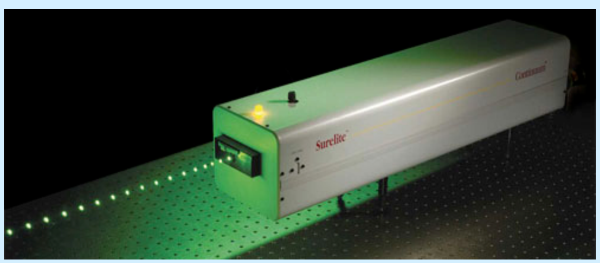


Boss

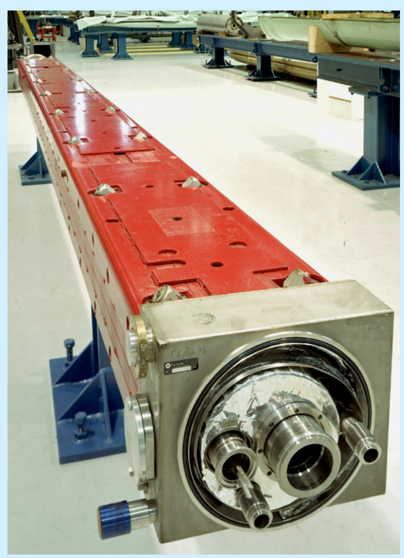
GammeV Design

Use a sliding plunger within a single accelerator magnet in order to vary the magnetic baseline and avoid regions of insensitivity in mass.





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

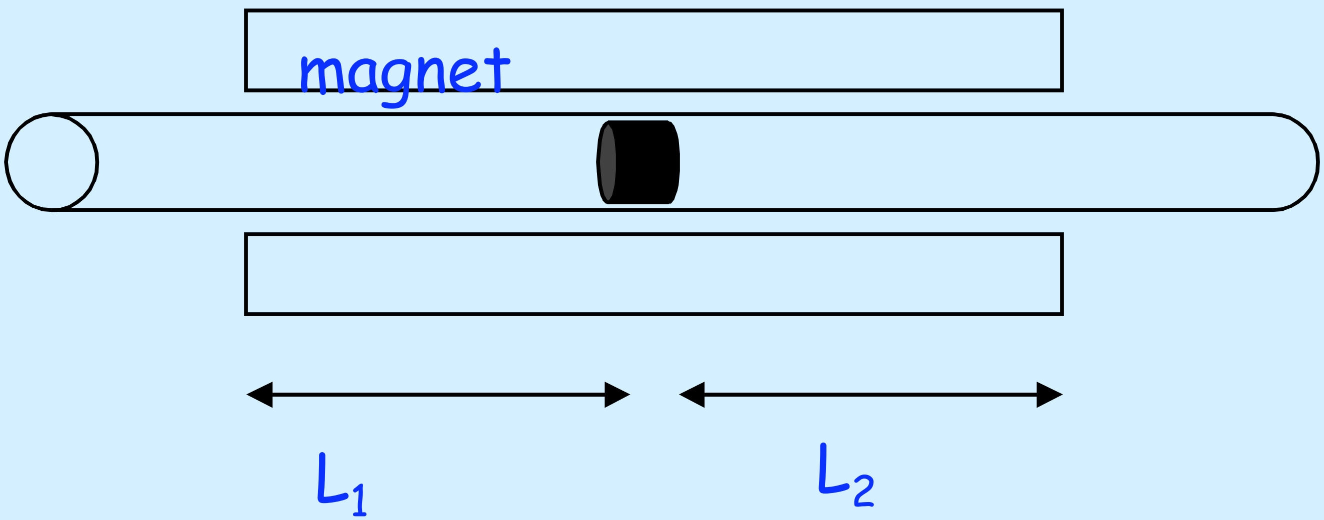


The "wall" is a welded steel cap on a steel tube with a mirror mounted in front.

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



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

L = distance traversed in B field

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

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

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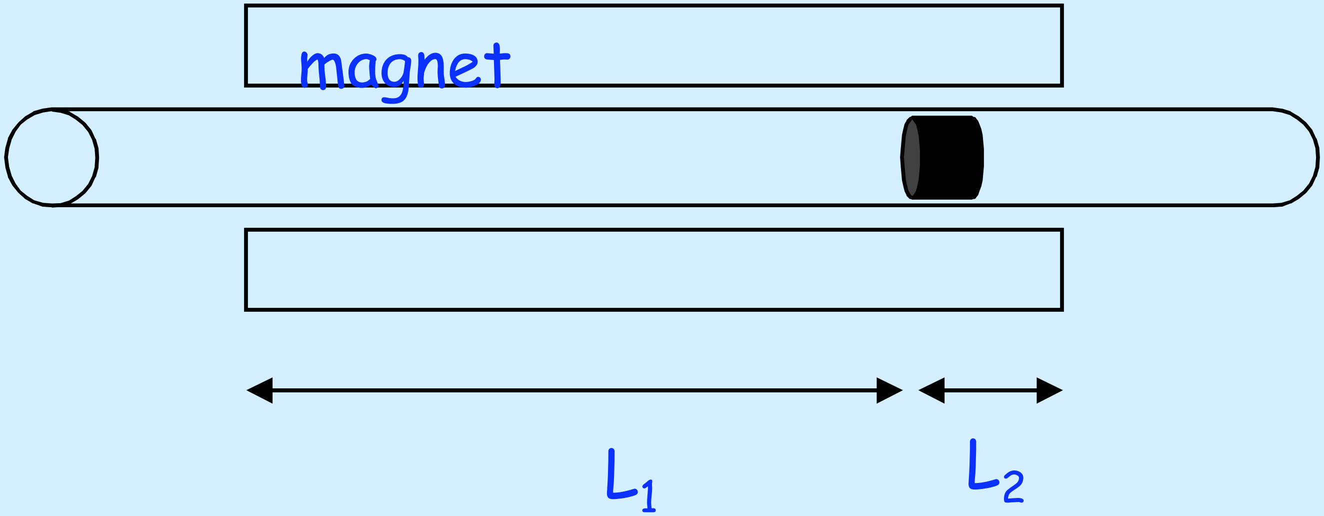

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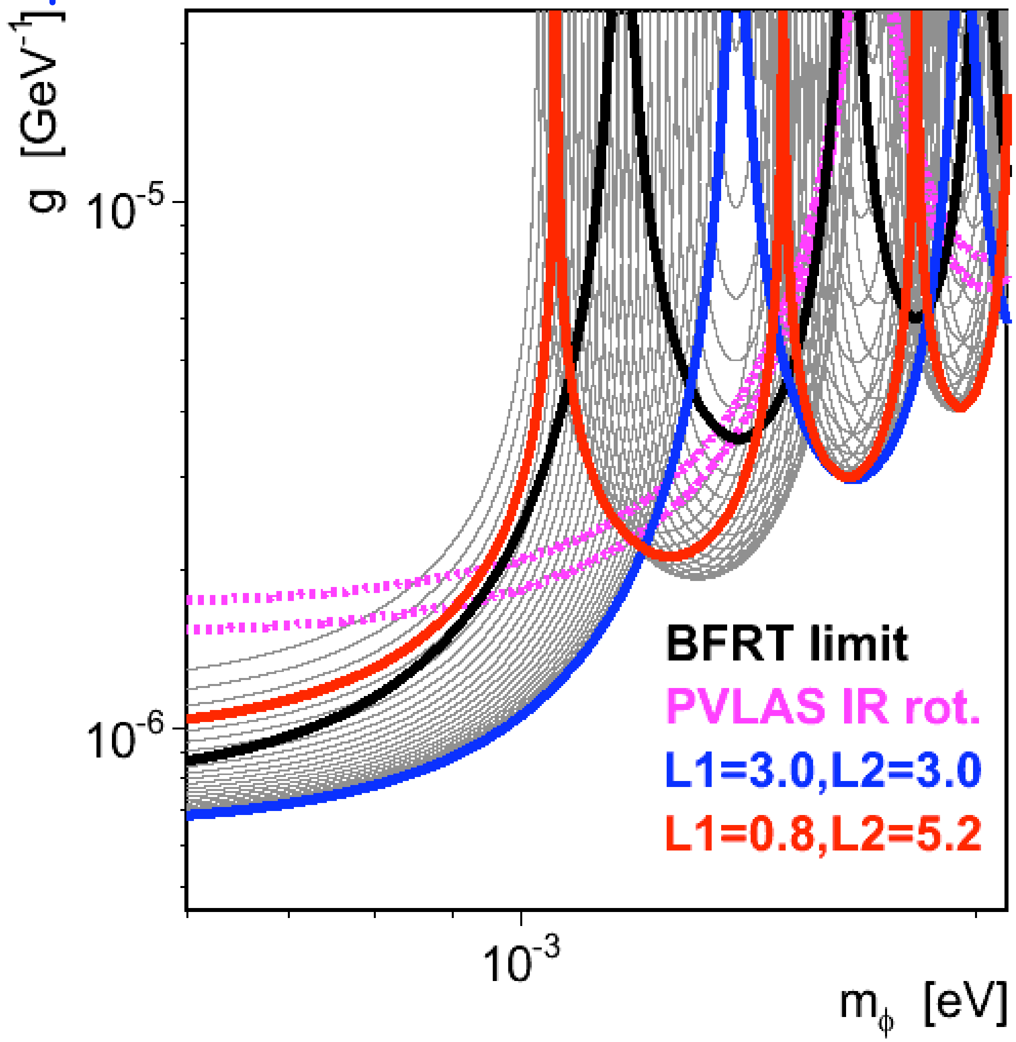
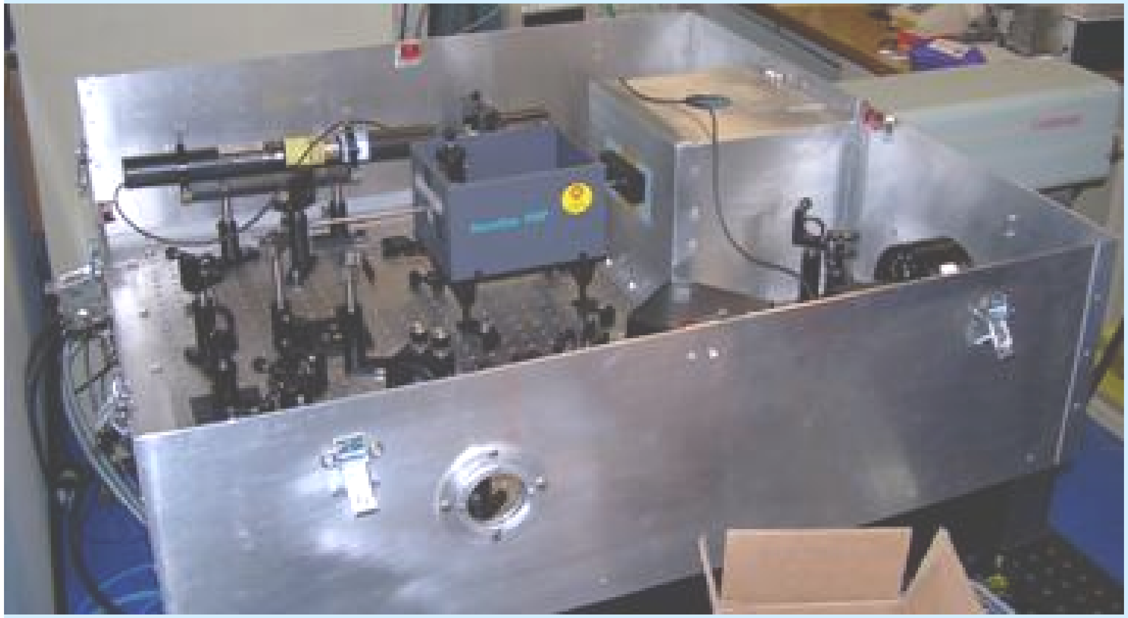
Expected Sensitivity to g=1/M

- Black = BFRT 3 sigma upper bound
- Pink = PVLAS 5 sigma signal region
- Grey = FNAL 3 sigma exclusion with 5 hours running at each beam dump position
  - Blue = center of magnet
  - Red = 0.8m from end
- **By changing the baseline, we cover the entire PVLAS signal region**

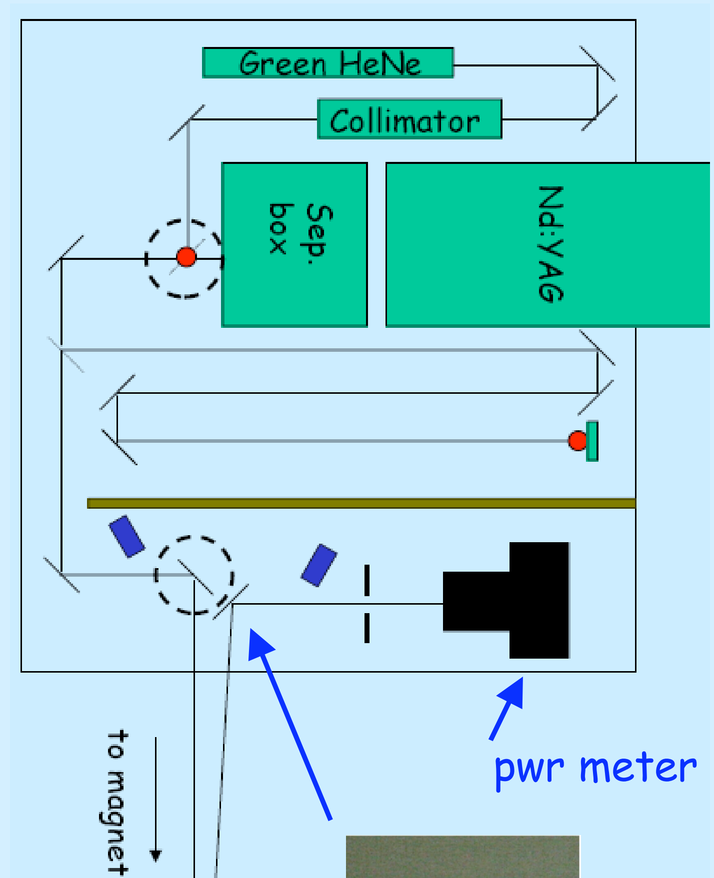
April Review



Use pulsed laser to beat down the dark noise



Laser box is safety interlocked, mounted on cement blocks, holds optics, and interfaces to vacuum inside the magnet.



pwr meter

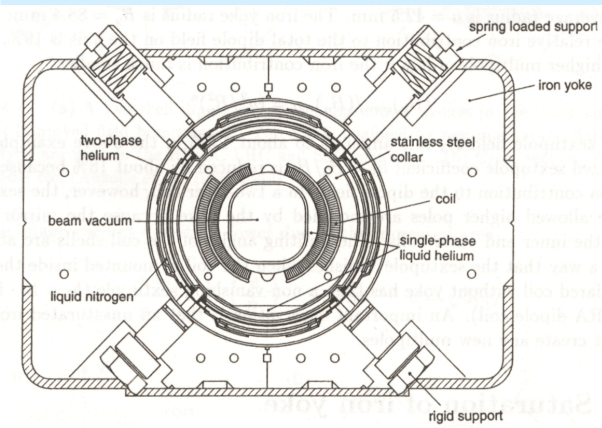
160mJ, 5ns pulses @20Hz of 532 nm light

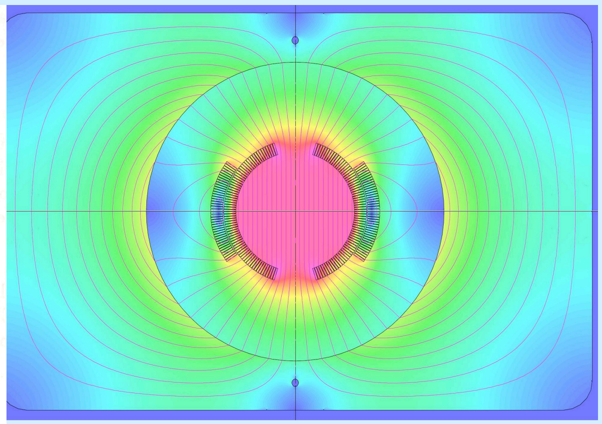
~ 10^{19} (2.33 eV) γ/s

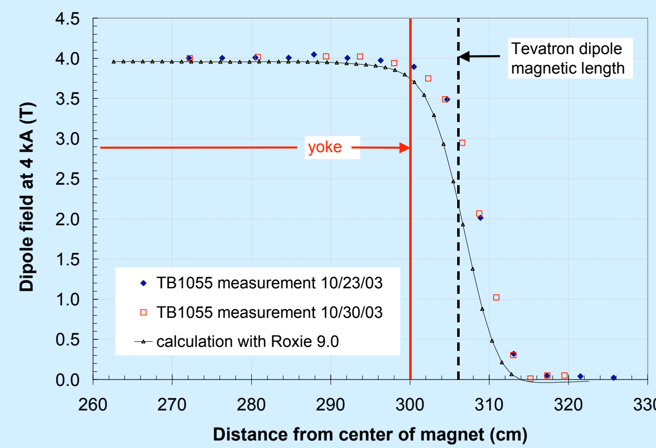
Recall: $P_{regen} \sim 10^{-21}$

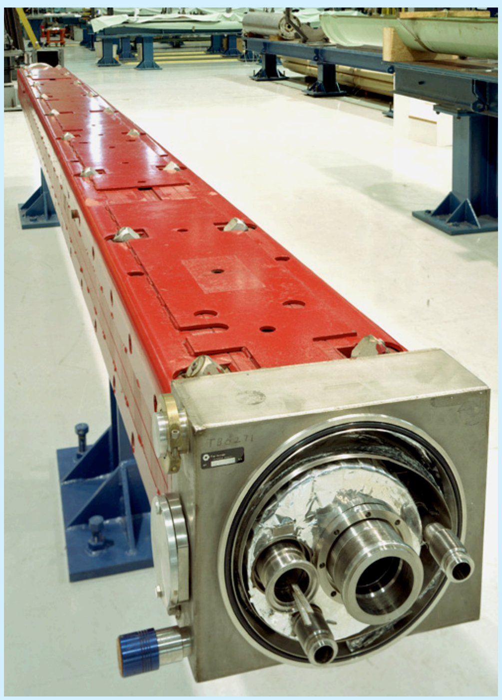
Reflected laser spot on mirror is monitored by video

Tevatron Magnet



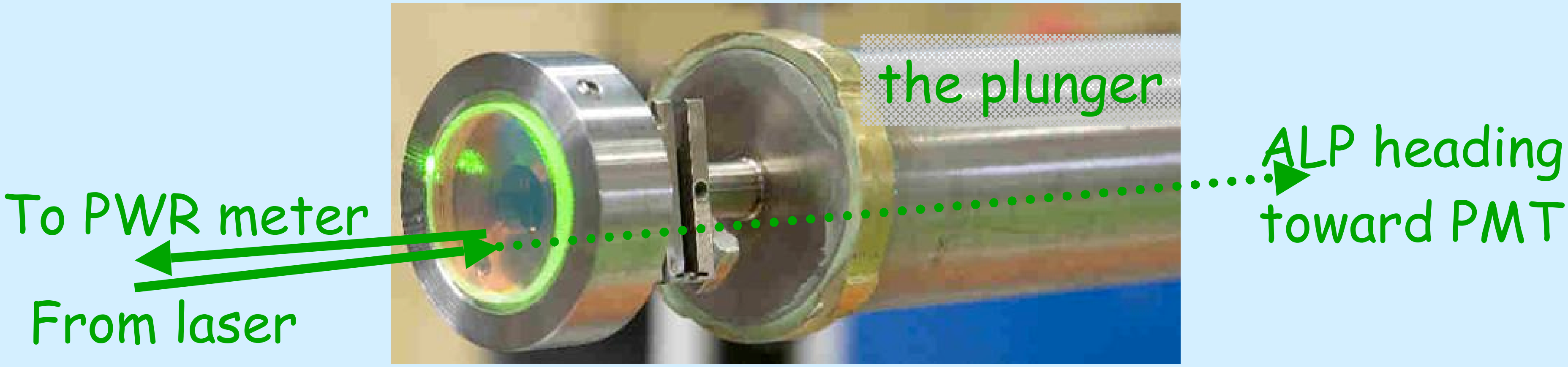


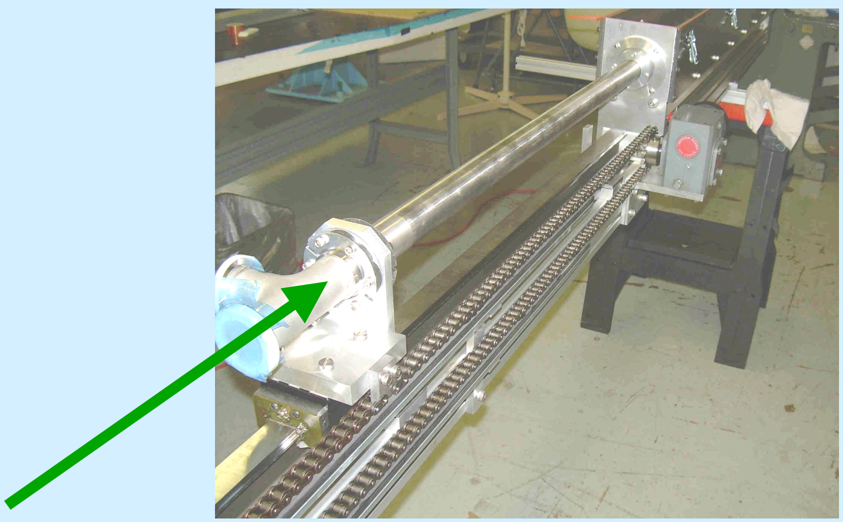




- Our magnet: TC1206 one of the best spare Tevatron dipole magnets. It was selected because it was previously run at high current
- Operating current was 5040A to have **5T over the entire 6m length.** Measured with NMR probes.
- Terrific support from the Fermilab Magnet Test Facility that gave us space and infrastructure on their test stand, and cryogenics support.

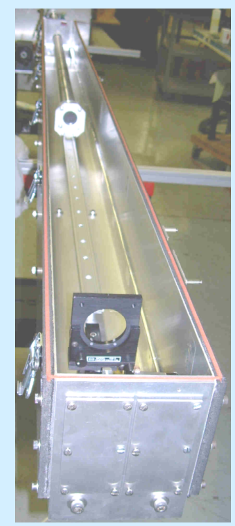
The "Wall" and plumbing





The plunger and PMT dark box design allows 2 meters of motion.

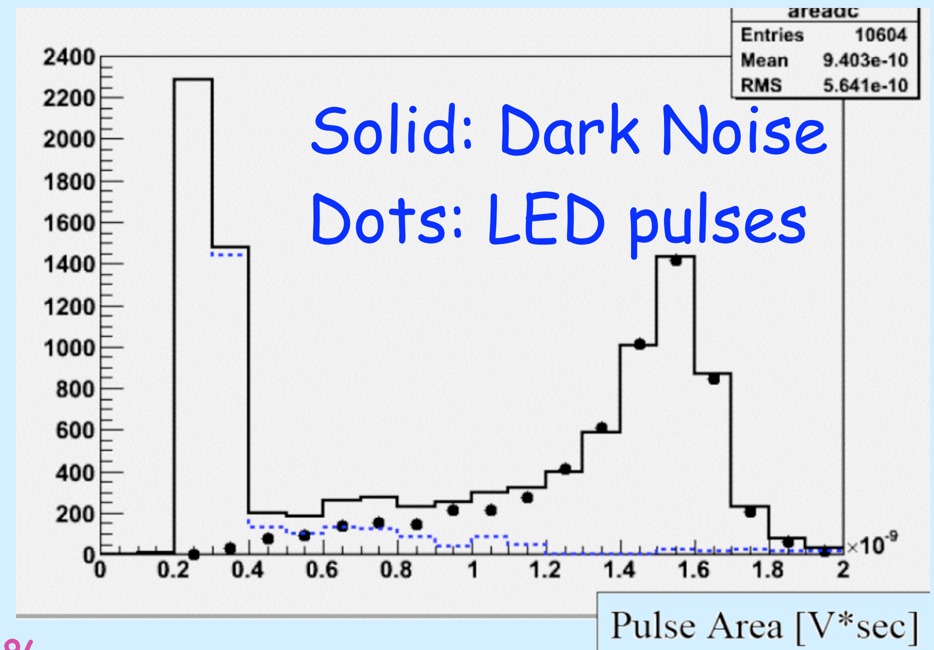
Two vacuum regions (inside and outside the plunger) are independently pumped to better than 10^{-4} torr.



Single photon detector

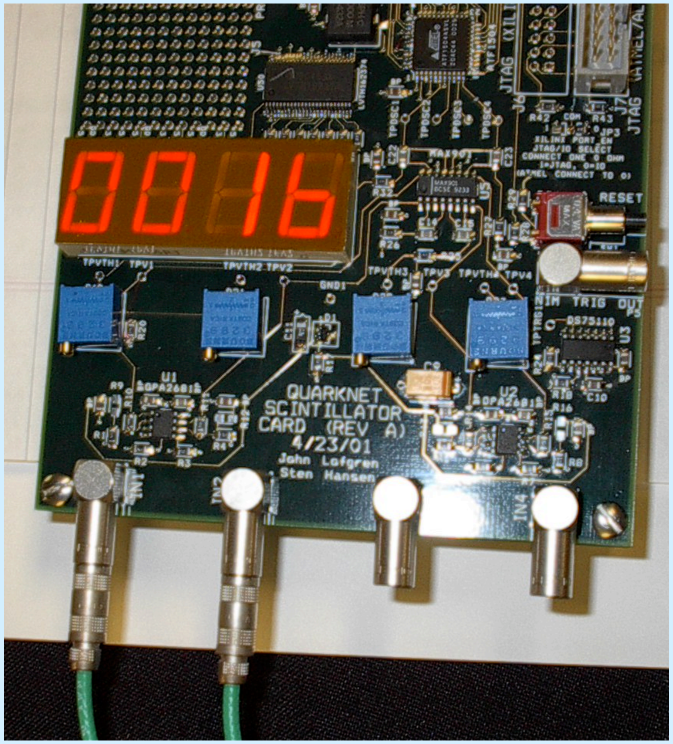
- Hamamatsu H7422P-40 PMT
- GaAsP photocathode, QE=40% at 532 nm
- **Dark Count rate ~ 100 Hz** with built-in thermoelectric cooler

We studied the response of the PMT using a single photon LED flasher system. There is a clear separation between noise dominated by the power supply and the single photo-electron peak.



Discriminator inefficiency (0.6+/-0.1)%

Coincidence counting with short laser pulses eliminates dark noise background



- QuarkNet timing cards
  - Built by Fermilab for Education Outreach (High school cosmic ray exp'ts.)
- Four inputs, phase locked to a GPS 1pps using a 100MHz clock that is divided by eight for **1.25ns timing.**
- Boards also send firing commands to the laser and LED pulser system
- Digital oscilloscope recorded PMT signals for LED photons and for rare coincidences.

Using **10ns** gates around the 20 Hz 5ns laser pulses:

Coincident noise rate =

100 Hz*20 Hz*10 ns = $2*10^{-5}$ Hz.

<< Expected signal ~ 10^{-3} Hz

GammeV

The competition

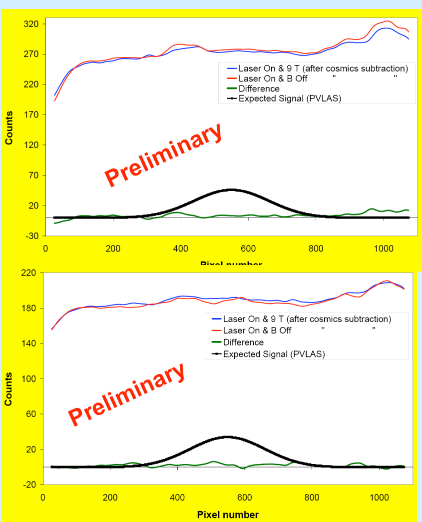
name	place	magnet (field length)	laser wavelength power	P_{PVLAS}	photon flux at detector
ALPS	DESY	5 T 4.21 m	1064 nm 200 W cw	$= 10^{-19}$	10/s
BMV	LULI	11 T 0.25 m	1053 nm 500 W 4 pulses/day	$= 10^{-21}$	10/pulse
LIPSS	Jefferson Laboratory	1.7 T 1.0 m	900 nm 10 kW cw	$= 10^{-23.5}$	0.1/s
OSQAR (preliminary phase)	CERN	9.5 T 1.0 m 9.5 T 3.3 m	540 nm 1 kW cw	$= 10^{-20}$	10/s
PVLAS (regeneration)	INFN Legnaro	5 T 1 m 2.2 T 0.5 m	1064 nm 0.8 W cw Npass $= 5 \times 10^5$	$= 10^{-23}$	10/s

CERN Courier

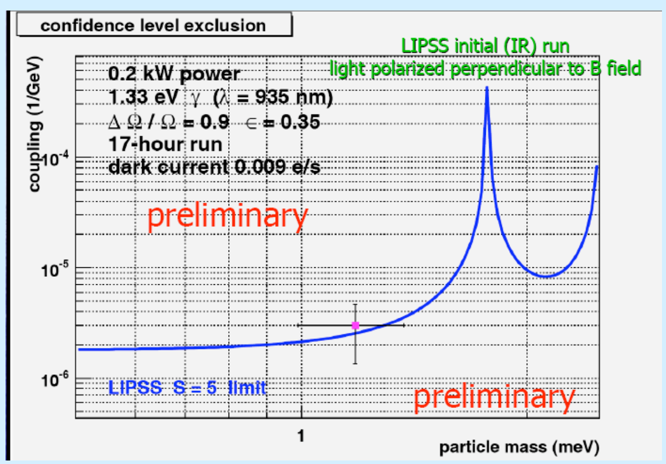
- World-wide effort to check the PVLAS signal (including PVLAS themselves).

The competition

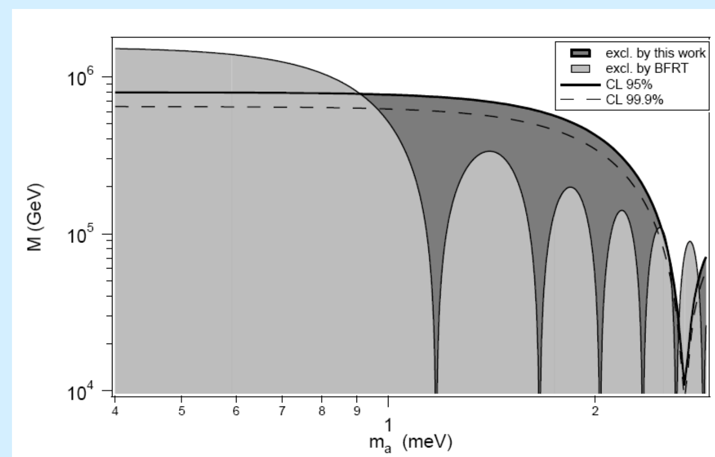
- OSQAR: null result for PVLAS scalar/pseudoscalar, but no limits set and they use a residual gas (not vacuum).
- LIPSS: begin to cover PVLAS region of interest for scalars
- BMV: Use 14 pulses (hep-ex/0707.1296) and cover PVLAS region of interest for pseudoscalar case. Only group with a current preprint.
- ALPS: Should also be taking data and have something to say soon?



OSQAR



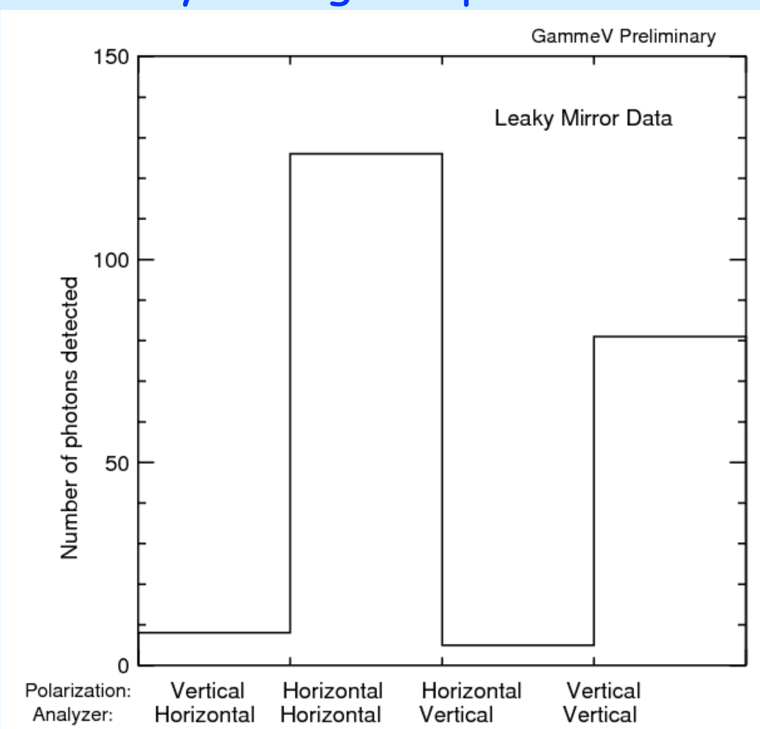
LIPSS

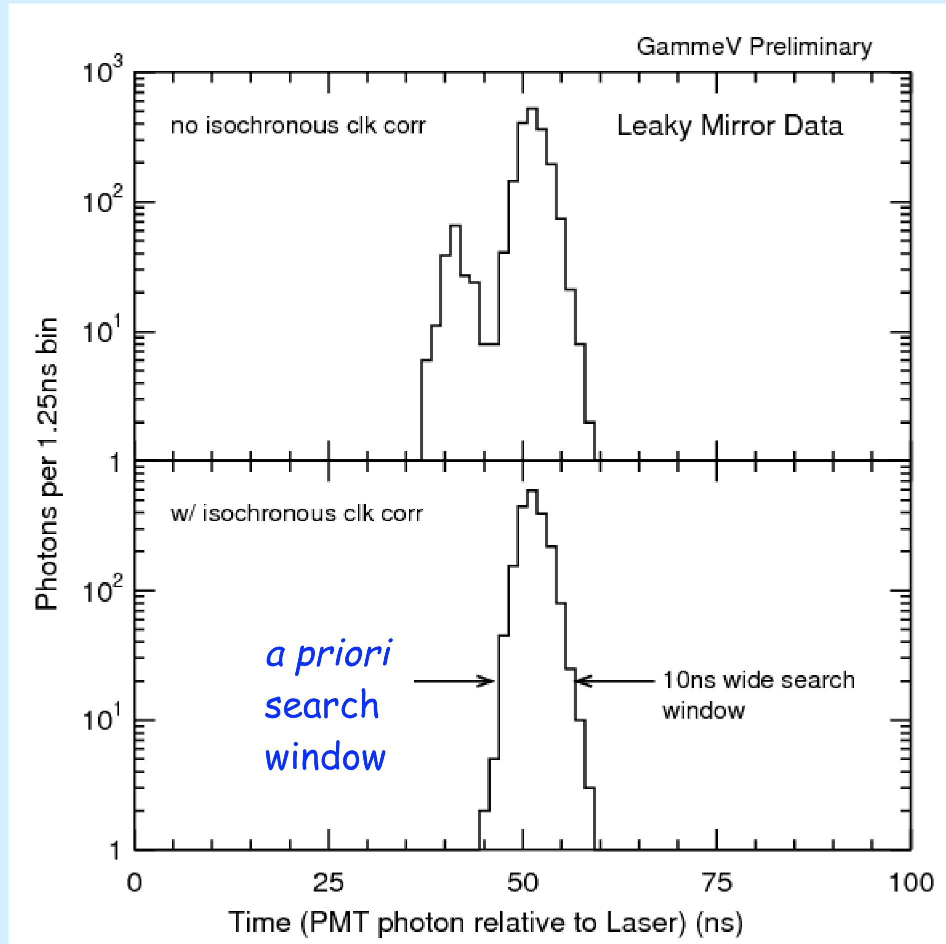


BMV

GammeV calibration

- "Leaky mirror" data involves sending the laser directly into our PMT after attenuation so that we get about 1 photon per 100 pulses.
  - Two mirrors leak ~10^{-6} through
  - 10 micron pin hole captures ~10^{-6}
  - Neutral density filters give ~10^{-7}
- Verify timing and polarization

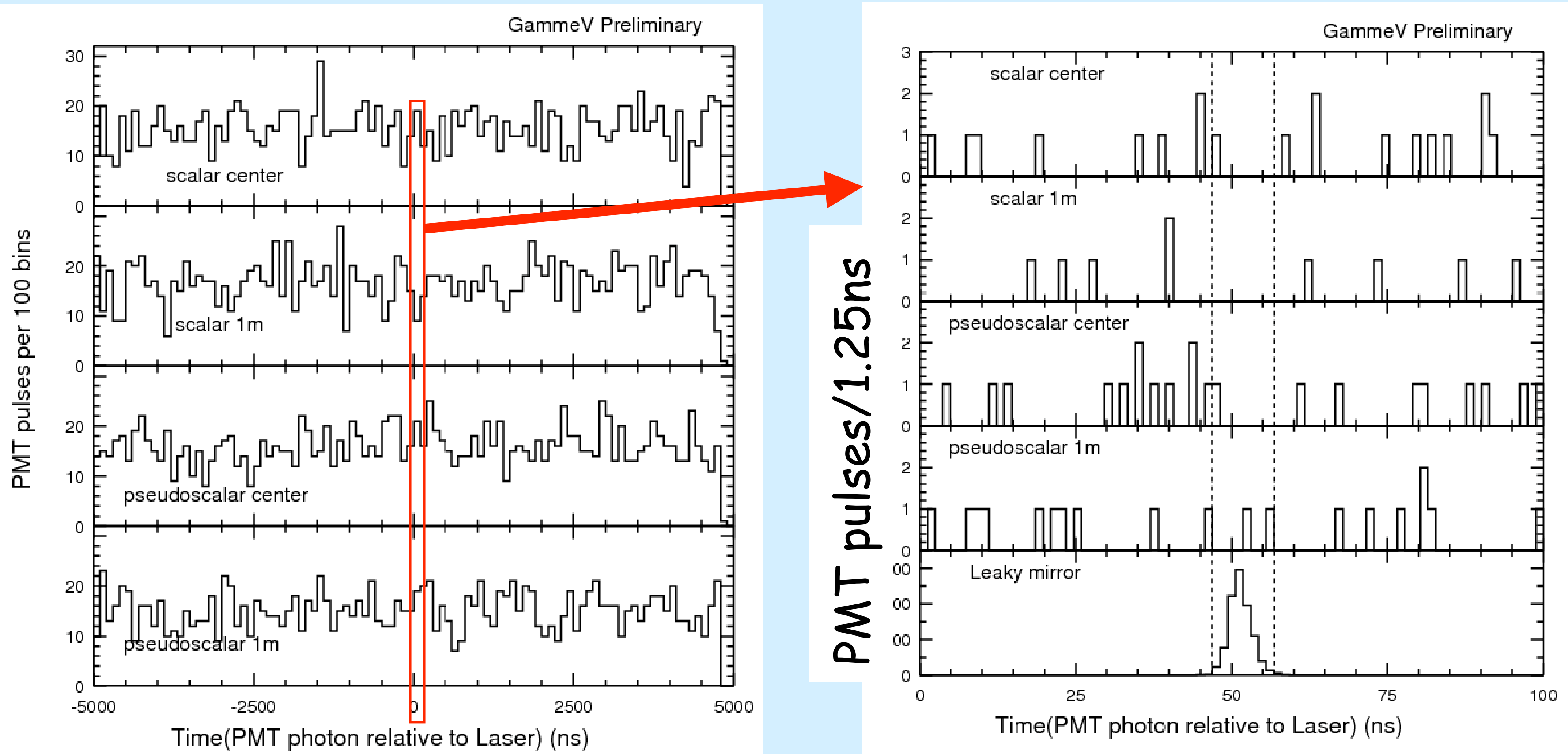




GammeV Data

- Take data in four configurations
  - (L_1, L_2) = (3.1m, 2.9m) or (5.0m, 1.0m) to cover all regions m_ϕ
  - Polarization = vertical or horizontal to cover both parities.
- 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
- Estimate the detection efficiency as:
  - QE 40% x CE 90% x transport 92% = (33 +/- 3.3)%
  - Optical transport efficiency measured to be ~92%
- Dark noise rate is measured by counting the non-coincident PMT triggers.

GammeV Data

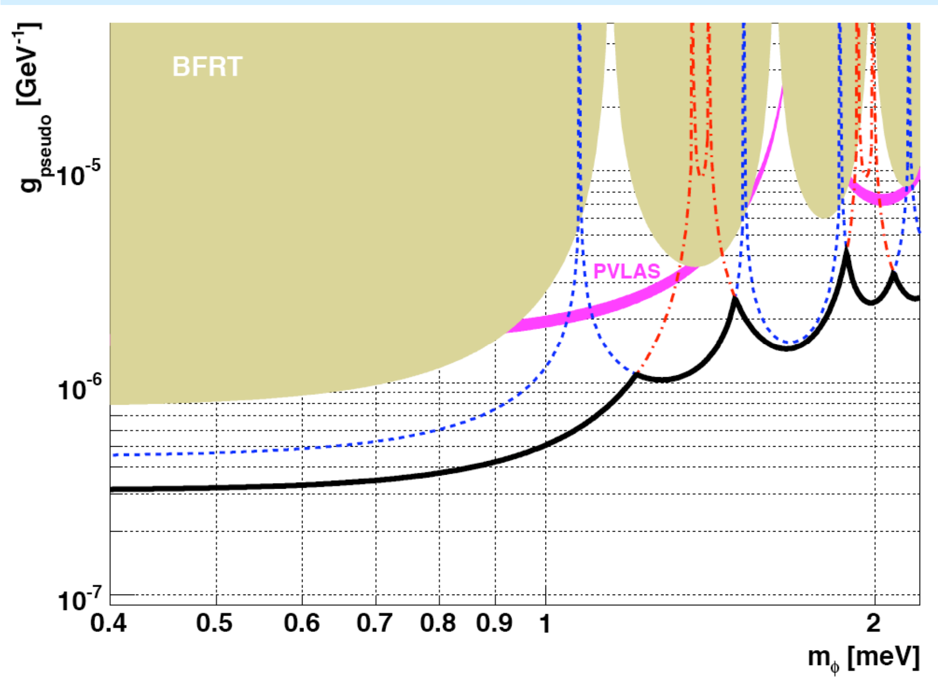


Configuration	# photons	Est.Bkgd	Signal	g[GeV^{-1}]
Horiz.,center	6.3×10^{23}	1.6	1	3.2×10^{-7}
Horiz.,edge	6.4×10^{23}	1.7	0	3.7×10^{-7}
Vert.,center	6.6×10^{23}	1.6	1	3.2×10^{-7}
Vert.,edge	7.1×10^{23}	1.5	2	4.5×10^{-7}

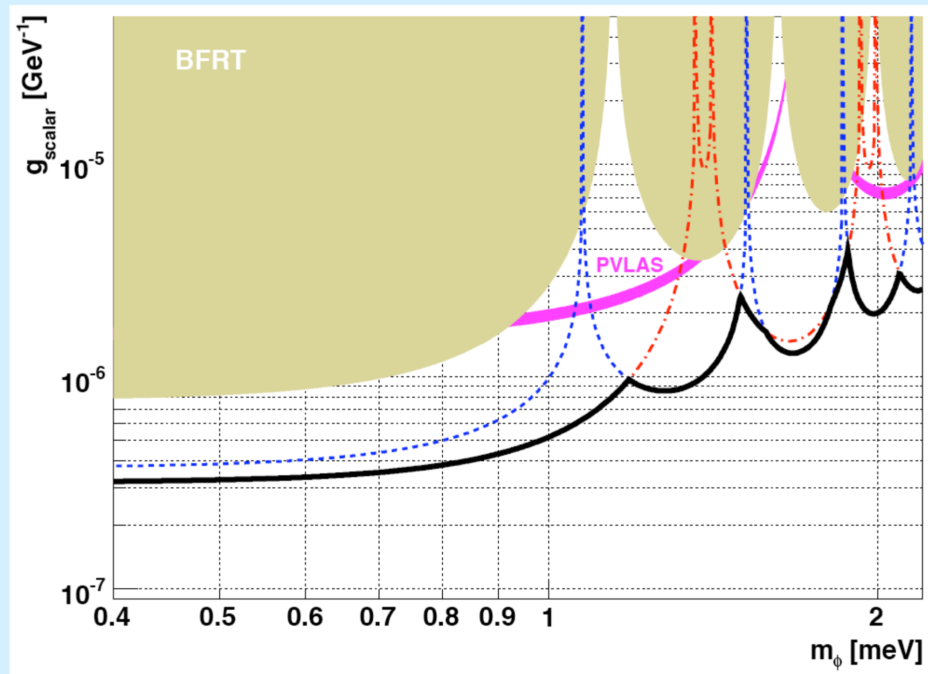
GammeV Results

Rolke-Lopez 3σ limits on g=1/M for **weakly-interacting axion-like particles**, w/estimated 14% systematic error on P_{regen}

Pseudoscalar



Scalar

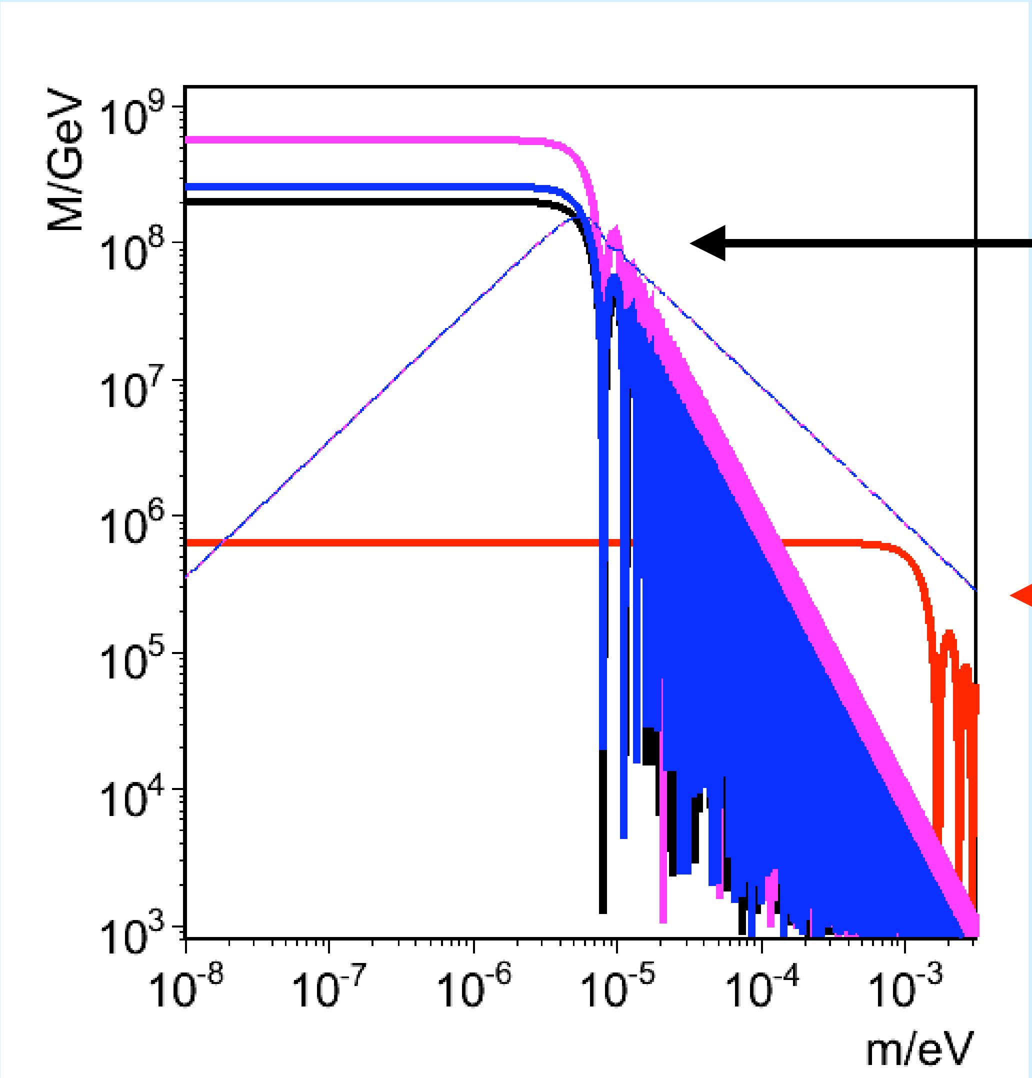


PVLAS region excluded by more than 5σ.

Failure mode of GammeV

- "Shining light through a wall" only works if the intermediate particles are weakly-interacting so that ***they pass through the wall***.
  - The plunger mirror then projects the reflected wave into a photon state and the transmitted wave into an scalar state.
- If the new scalars have strong matter effects such that the effective mass inside the ~1 g/cm^3 material of the mirror is greater than the total particle energy, then ***they reflect just like photons***.
  - The plunger mirror makes no wavefunction reduction, and both components of the wave are reflected.
  - In the PVLAS apparatus, the oscillation continues for all ~42000 passes in the cavity.
  - **The wavefunction is reduced at the exit window which projects the reflected wave into scalars and the transmitted wave into photons.**

PVLAS reinterpreted



Reflective scalars have a baseline of ~42000 m

Best fit region:

$g \sim 10^{-8}$ GeV^{-1}

$m_\phi \sim 6\ 10^{-6}$ eV

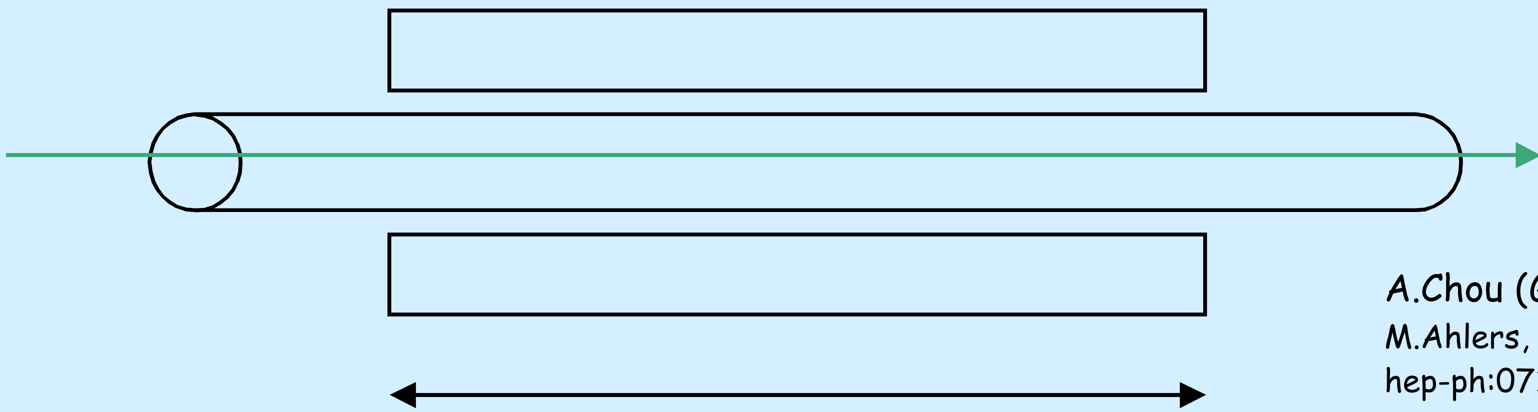
J. Jaeckel, et.al

Phys Rev D75:013004 (2007)

In the standard ALP interpretation: Weakly-interacting scalars have a baseline of 1 m, but 42000 passes.

Particles trapped in a jar

Remove plunger and just use clear vacuum windows on each side



L = 6 meters

A.Chou (GammeV)
M.Ahlers, et.al,
hep-ph:0710.1555

H.Gies,D.Mota,D.Shaw,
hep-ph:0710:15556

- Shine laser through to a beam dump in the PMT box. Oscillations will populate the "cavity" with reflective scalars.
- Due to their low energy, the scalars cannot efficiently transfer energy to the windows or walls of the cavity. (Mossbauer effect)
- Turn off laser, and look for afterglow of scalars oscillating back into photons.

GammeV

Some numbers, assuming $M=10^8$ GeV

- For small scalar mass, $$P_{\gamma \to a} = 4 \frac{B_{\text{ext}}^2 \omega^2}{M^2 m_a^4} \sin^2 \left[\frac{m_a^2 l}{4\omega} \right] \cong \frac{B_{\text{ext}}^2 l^2}{4M^2}$$

$= (10^3\ eV^2)^2\ (6m * 5*10^6/m*eV)^2/4*(10^{17}eV)^2 =$ **$3*10^{-14}$**

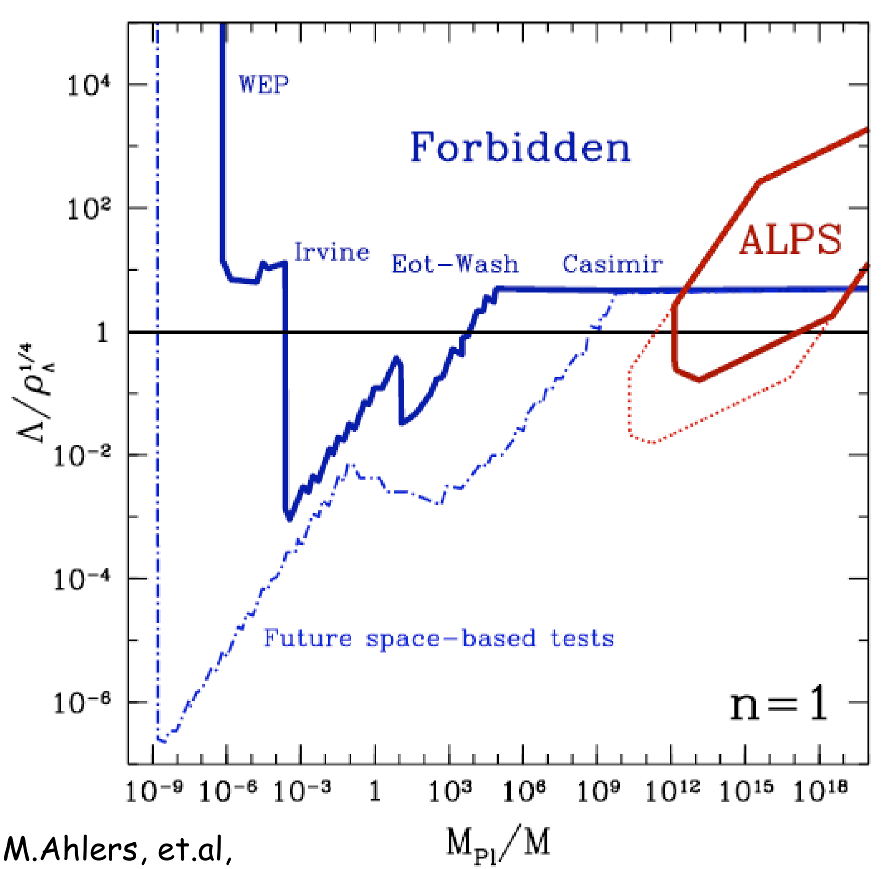
For 10^4 seconds of integration, **cavity population** will be:
10^{19} g/s * $3*10^{-14}$ * 10^4 s = **$3*10^{10}$ ϕ's**

Density = $3*10^{10}$ phis/$1.2*10^4$ cm^3 = **$2.5*10^6$ ϕ's /cm^3**
Rate of waves impacting mirror ~ Density*c/3 * $20cm^2$ = $6*10^{17}$/s
Rate of regenerated photons passing through windows
= $6*10^{17}$/s * $3*10^{-14}$ = **$2*10^4$/s**
Optics transport efficiency ~ photocathode area/window area = 1%
Rate of detected photons = $2*10^4$/s * 1% * 40%QE = 80 Hz,

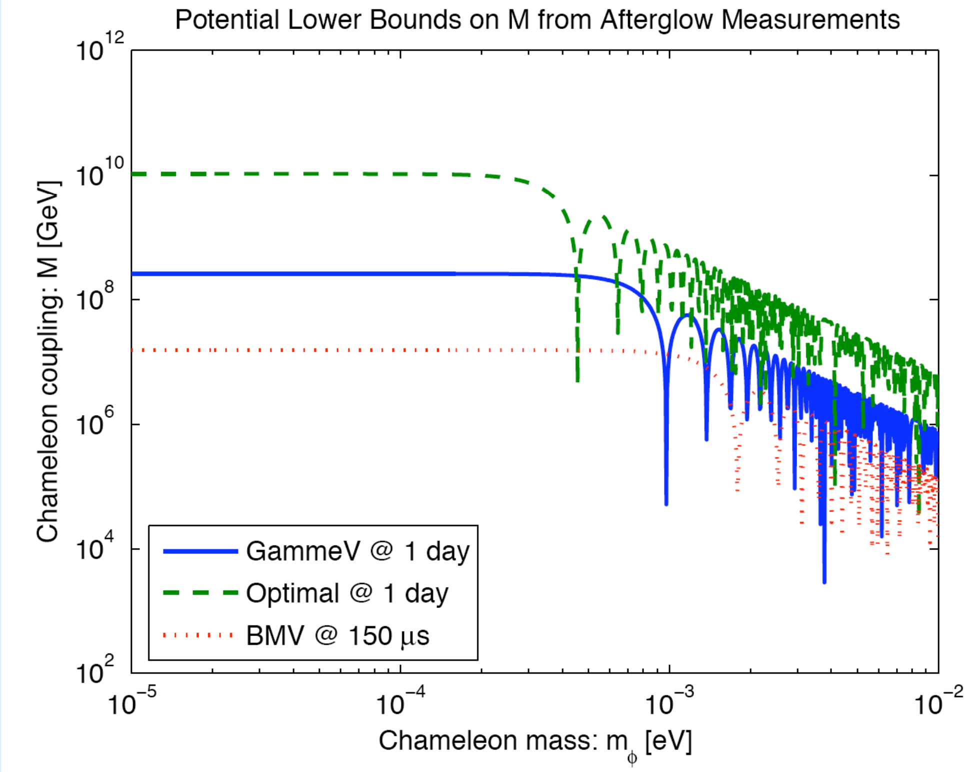
Easily detectable above the <10 Hz dark rate of a cooled PMT.

GammeV

Reach of chameleon searches



M.Ahlers, et.al, hep-ph:0710.1555



H.Gies,D.Mota,D.Shaw, hep-ph:0710:15556

GammeV

Conclusions

- GammeV convincingly excludes at 5σ the axion-like-particle interpretation of PVLAS data for both scalar and pseudoscalar particles
  - Not terribly surprising due to stringent limits from star cooling, gravitational ISL, etc.

- In the second stage of the experiment, we will search for reflective particles with strong matter effects with a novel new technique: **"Particles trapped in a Jar"**
  - Chameleons, dilatons, etc which evade other experimental bounds
  - Large regions of parameter space can be tested
  - Chameleon models and new scalars mediating neutrino-neutrino interactions may be related to the accelerated expansion of the universe.