Gam\textsubscript{me}V

**Gamma to milli-eV particle search**

William Wester, Fermilab
for the \textbf{GammeV} Collaboration
milli-eV Mass Scale

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

Energy frontier
Neutrinos
Astrophysics
all in one!
Gam\textsubscript{meV}\n
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\times10^{-6}. New data->no anomaly.

PVLAS rotation anomaly reported: PRL 96, 110406 (2006)
Previous laser experiment

- Brookhaven, Fermilab, Rochester, Trieste (1992)

BFRT is not sensitive in the PVLAS region of interest.
GammeV

Light Shining Through a Wall Experiment


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

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

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

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

\[ P_{\text{regev}}^{\text{GammeV}} = (3.9 \times 10^{-21}) \times \frac{(B_1/5\,\text{T})^2(B_2/5\,\text{T})^2(\omega/2.33\,\text{eV})^4}{(M/4 \times 10^5\,\text{GeV})^4(m_\phi/1.2 \times 10^{-3}\,\text{eV})^8} \]

\[ \times \sin^2 \left( \frac{\pi (m_\phi/1.2 \times 10^{-3}\,\text{eV})^2(L_1/2.0\,\text{m})}{2(\omega/2.33\,\text{eV})} \right) \sin^2 \left( \frac{\pi (m_\phi/1.2 \times 10^{-3}\,\text{eV})^2(L_2/2.0\,\text{m})}{2(\omega/2.33\,\text{eV})} \right) \]

7/30/2008
W. Wester, Fermilab, ICHEP 2008, Philadelphia PA
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

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

Existing laser used by the Accelerator Division.

High-QE, low noise, fast PMT module (purchased)
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 ½-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

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

**GammeV Preliminary**

- **Scalar Center**: 1.34 M, 0.41e18 photons/pulse, 1.56±0.04 expected background, 1 signal candidate.
- **Scalar 1 m**: 1.47M, 0.38e18 photons/pulse, 1.67±0.04 expected background, 0 signal candidates.
- **Pseudo Center**: 1.43M, 0.41e18 photons/pulse, 1.59±0.04 expected background, 1 signal candidate.
- **Pseudo 1 m**: 1.47M, 0.42e18 photons/pulse, 1.50±0.04 expected background, 2 signal candidates.
GammeV Results

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

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.

GammeV

OSQAR
hep-ex/0712.3362
Note: with N₂ gas

W. Wester, Fermilab, ICHEP 2008, Philadelphia PA

7/30/2008
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.

Generate 100% reflective chameleons due to strong matter coupling.

Turn off laser and look for a regenerated photon afterglow.

Valid for a limited range of potentials
Next future steps?

Resonantly enhanced axion-photon regeneration

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.

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

Sikivie, Tanner, van Bibber
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.

gammev.fnal.gov