PROBING PHOTON–MAGNETIC FIELD COUPLING VIA HIGH-RESOLUTION ^{241}Am SPECTROSCOPY WITH A $CeBr_3$ DETECTOR

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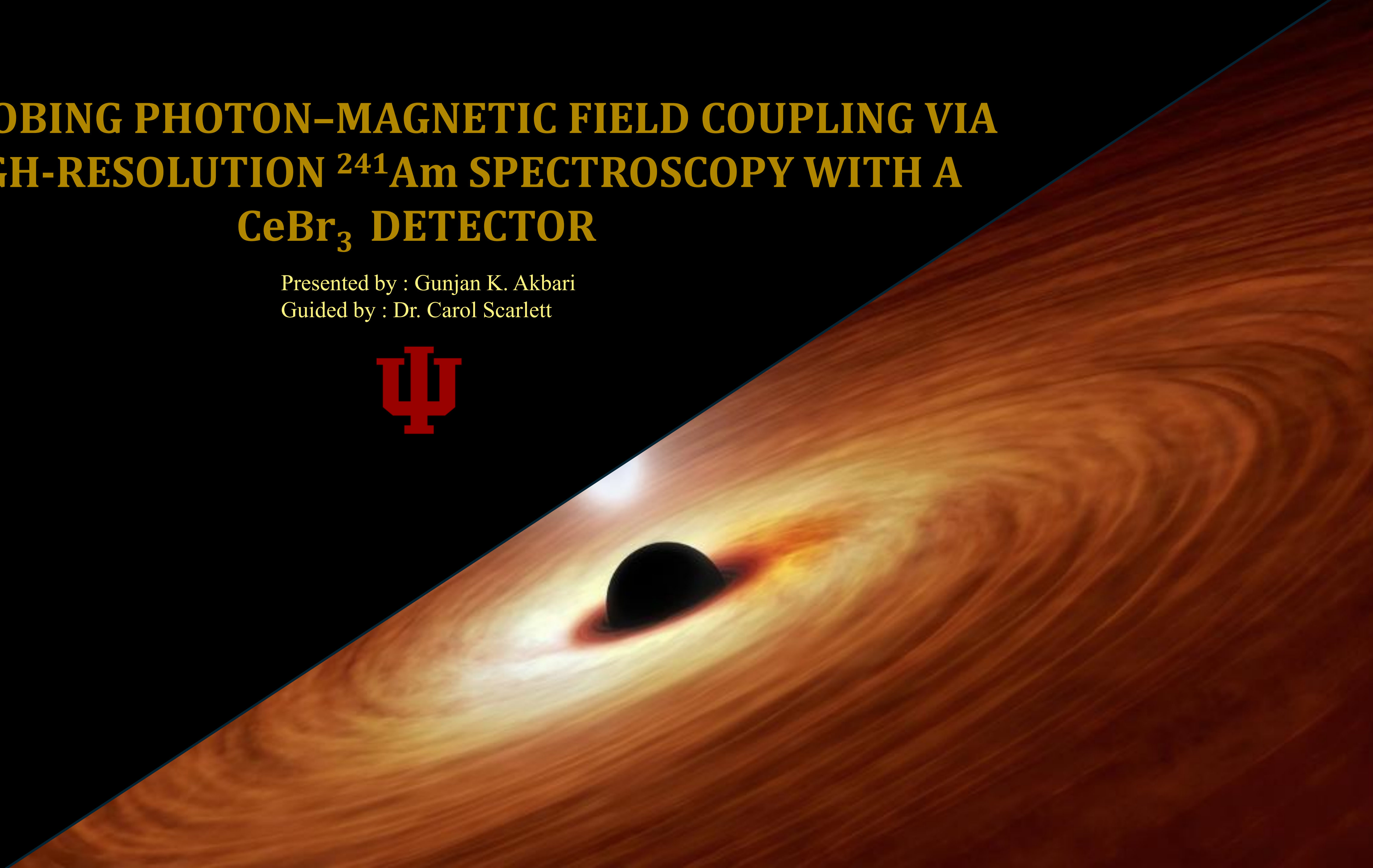


Talk Overview

1. Motivation

Why the dark sector points us toward axion-like particles

2. Theory

The Primakoff effect: photons convert to weakly interacting particles in a magnetic field

3. Experiment

Apparatus, field geometry, and measurement modes

4. Analysis

Extracting a statistically significant signal from ^{241}Am decay

5. Results

A reproducible, geometry-dependent decay modulation

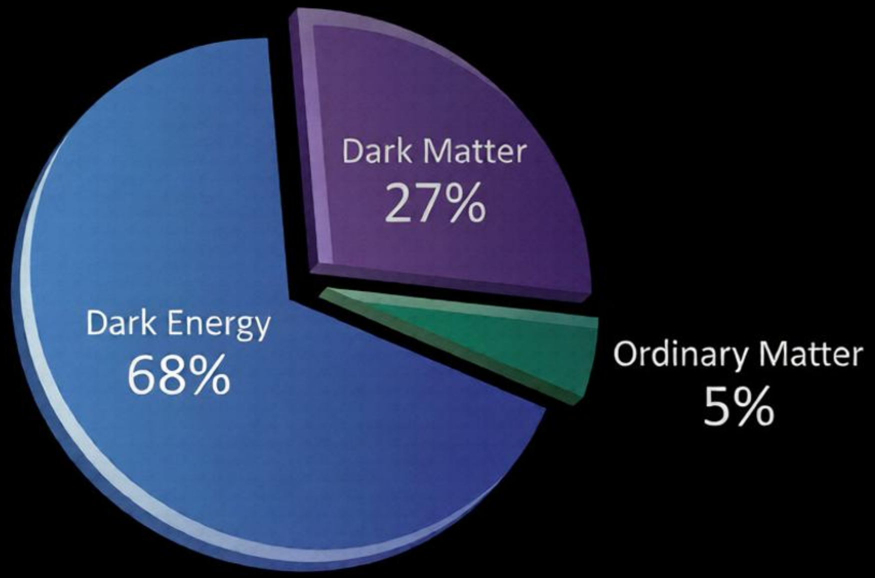
6. Outlook

Cross-section estimates, implications, and next steps

What Could Dark Matter Be Made Of?

Only 5% of the universe is ordinary matter. Leading candidates for the rest of the dark sector:

Composition of the Universe



WIMPs
Weakly Interacting Massive Particles which have long been the leading candidate

Sterile Neutrinos
Right-handed neutrinos that interact only via gravity and mixing

Axions / ALPs
Ultra-light pseudoscalar bosons predicted to couple weakly to photons
Theorized to explain neutron EDM absence

Axions can interact with photons in the presence of a magnetic field, and this is the coupling our experiment searches for.

The Strong CP Problem and the Axion

- CP violation has been measured in the weak interaction, but never in the strong interaction which is a long-standing puzzle.
- This is compounded by the absence of a measurable neutron electric dipole moment (nEDM), which should arise from the quark content of nucleons.

Peccei–Quinn Solution (1977)

A new scalar field coupling to fermions to resolve both puzzles and predicts a new boson: the axion.

R. Peccei & H. Quinn, Phys. Rev. Lett. 38, 1440 (1977)

No strong CP violation observed

+ No measurable neutron EDM

→ Peccei–Quinn scalar field

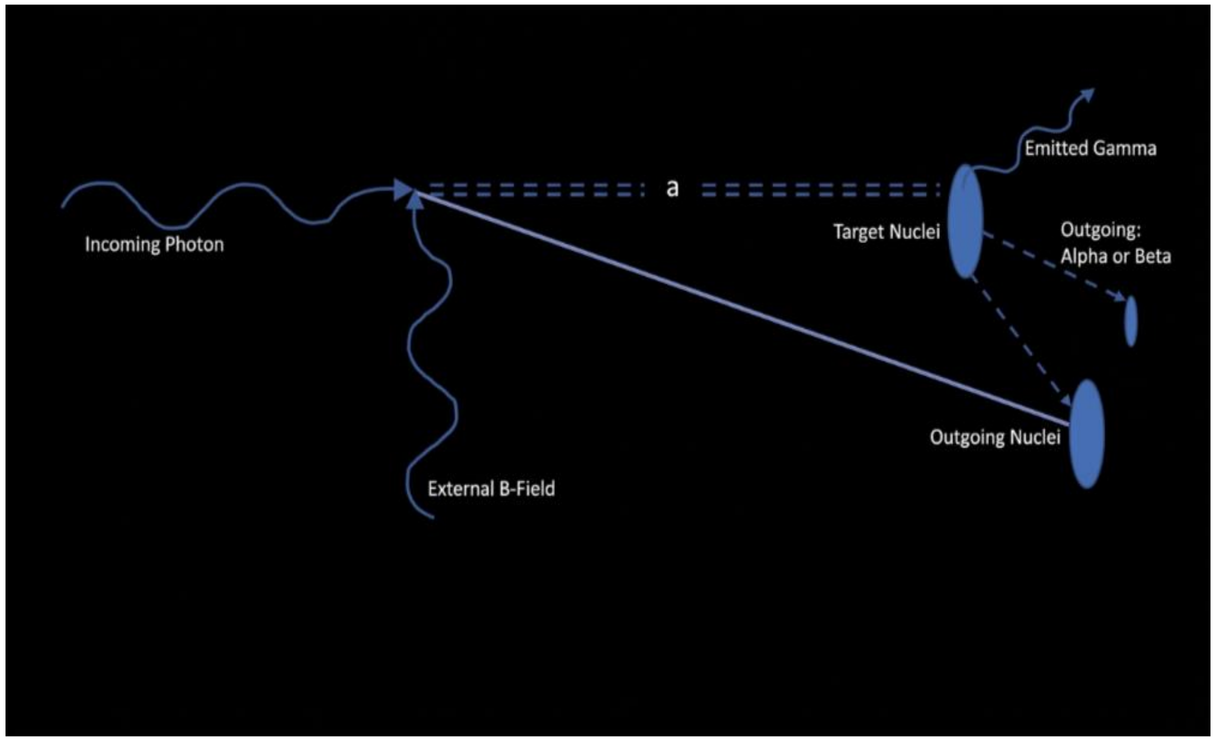
→ Predicts the axion boson

→ Axion interacts to photons + B-field

This experiment tests the last step directly: does an axion-like particle, produced via a photon B-field interaction, leave a measurable trace?

The Primakoff Effect

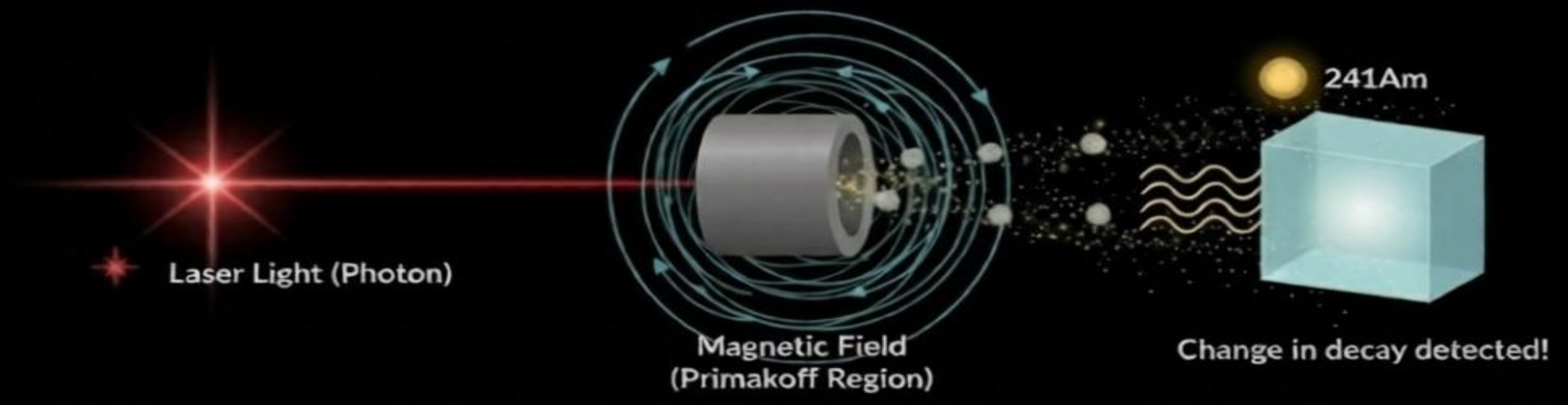
The Primakoff Mechanism



- Proposed by Henry Primakoff (1951) to explain photo-production of mesons in a nucleus's Coulomb field.
- A photon interacts with a virtual photon from an external B-field and converts into a pseudoscalar boson (e.g. an axion).
- The B-field breaks the isotropy of space, allowing the otherwise-forbidden conversion.
- Basis of major optical axion searches are PVLAS, BMV, BNL E840, none of which has yet confirmed a detection.

A New Approach: Probing Nuclear Decay

Other searches ask, Does the light change? We ask, **Does this interaction go one step further? Does it reach all the way to a nucleus, and change how that nucleus decays?**



The particle itself is invisible to us. What we measure is a small shift in how many gamma rays the source emits.

Experimental Concept

A continuous laser beam is threaded through a magnetic cavity aimed at a radioactive source, while a shutter allows us to switch between two conditions:

sP — Light Mode

System–Photons

Laser photons are allowed to pass freely through the magnetic cavity toward the target.

sD — Dark Mode

System–Dark

The beam is mechanically blocked before entering the cavity : no photons, no ALP production.

A barrier at the cavity exit keeps direct light from ever reaching the source. So, only a weakly interacting particle could cross it. Comparing gamma counts between the two modes isolates that effect.

The Apparatus: Magnetic Cavity

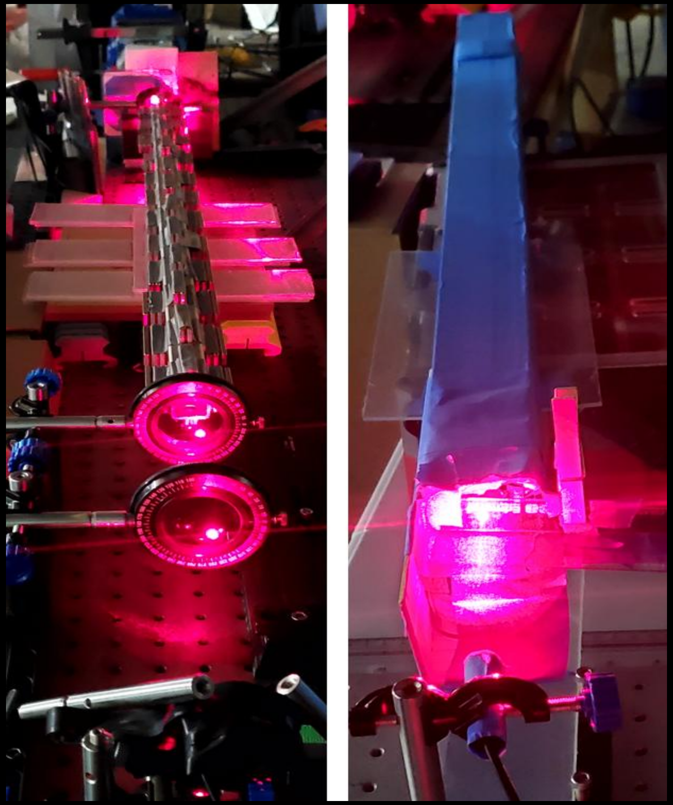


Fig. 3 : Laser threading the magnetic cavity (left) and the cavity exit barrier (right)

- NdFeB permanent magnets create a static field of ~50–130 mT over a path length of approximately 1 meter.
- A continuous-wave laser threads the full cavity length; the beam is always on to avoid electronic switching artifacts.
- A barrier at the cavity exit blocks direct light from reaching the radionuclide placed downstream.
- Two independent builds were tested: Experiment 1 (632 nm, red laser) and Experiment 2 (445 nm blue laser, mirror cavity).

The photos above are the real apparatus, and the red beam path is the 632 nm laser passing through the magnet cavity.

Field Geometry: BH and BV Modes

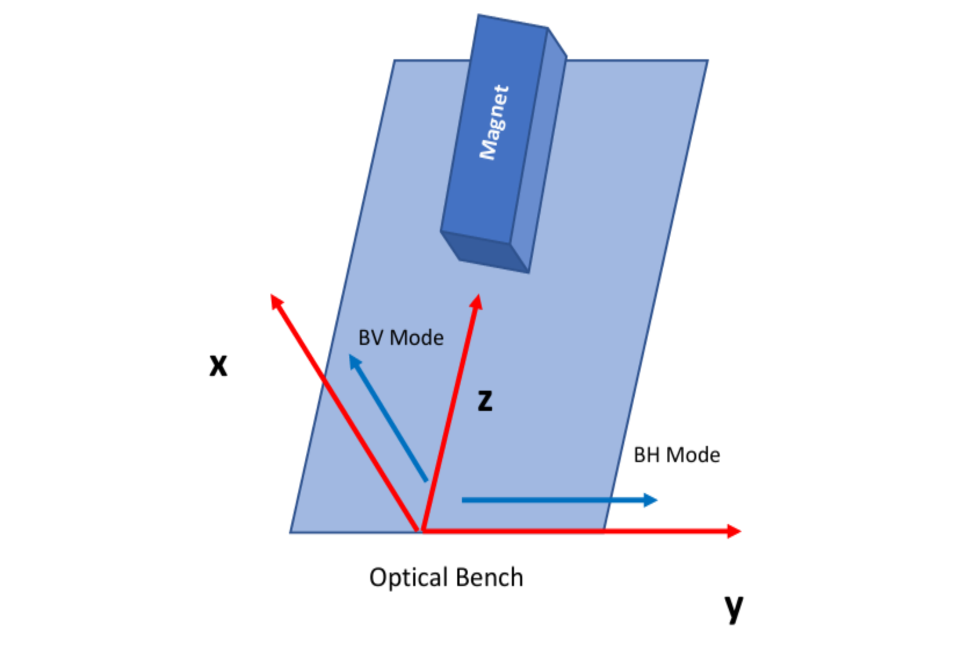


Fig. 4 : Laser propagates along z, polarized along y; the magnet rotates between BH and BV configurations

BH — Field ‖ Polarization

B-field aligned with the y-axis laser polarization. E·B ≠ 0. So, ALP production is allowed. This is the high-signal configuration.

BV — Field ⊥ Polarization

B-field rotated to the x-axis, perpendicular to polarization. E·B = 0. So, the built-in null test / control configuration.

Measurement Modes and Background Control

Timing & Switching

- sP and sD are alternated on a fixed schedule (1 hour in Exp. 1, 15 minutes in Exp. 2) to cancel slow drifts.
- The magnet orientation (BH or BV) is fixed for the full duration of a given run and set once, no switching mid-scan.
- The primary NaI detector is calibrated on the 59.54 keV line and records both sP and sD spectra.

Background Subtraction

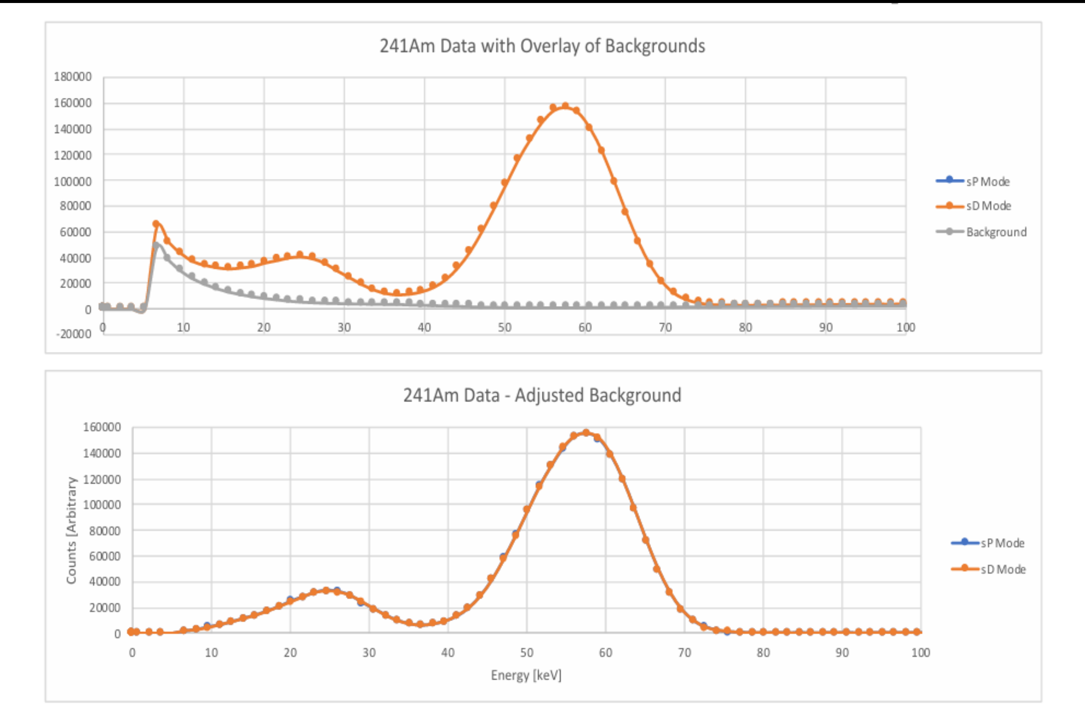
- A second detector continuously monitors room background, independent of the experimental detector.
- Because the two detectors have different natural calibrations, the experimental detector is also run “No Source” in both sP and sD to fix the background amplitude directly.
- That No-Source spectrum is subtracted from both modes, isolating drift, temperature, and electronics-independent effects.

Result: only the No-Source-subtracted, mode-alternated spectrum from the experimental detector is used to calculate the final ^{241}Am energy spectrum

Experimental Parameters

Parameter	Experiment 1	Experiment 2
B-field strength	50–80 mT	130 mT
Field length	≈ 1 m	≈ 1 m
Laser	632 nm, 1 mW × 6 beams	445 nm (blue), 1 mW, mirror cavity
Source	^{241}Am, ~100 cnts/s, 1 mm	^{241}Am, ~100 cnts/s, 1 mm
Mode switch interval	1 hour	15 minutes
Total integration time	60 hours	48 hours
Detector	NaI, calibrated at 59.54 keV	New NaI detector set

Gamma Spectrum of ^{241}Am



- Two dominant features: a strong peak at 59.54 keV and a smaller peak at 26.32 keV, matching the ^{237}Np gamma lines.
- Background is removed using the “No Source” subtraction described previously.
- At this resolution, sP and sD are visually indistinguishable and there is no obvious difference between light and dark modes.

~0.33%

The size of the effect hiding in this spectrum which is roughly 10 thousand counts out of 3 million. This revealed only after statistical processing.

Statistical Analysis Method

1

Compute the difference

Δ = sD − sP as a function of energy, bin by bin across the spectrum.

2

Set the window width

Find the FWHM of the 59.54 keV peak; use it as a 12-bin sliding window.

3

Slide & score

Slide the window across the spectrum, computing a local statistical significance σ at each position.

4

Threshold

Bins with $\sigma < 4.5$ are set to zero, suppressing noise-level fluctuations from the display.

Any surviving peak in σ that lines up with the known 59.54 keV gamma line is a candidate for a real sP–sD difference not statistical noise.

Signal Observed in BH Mode

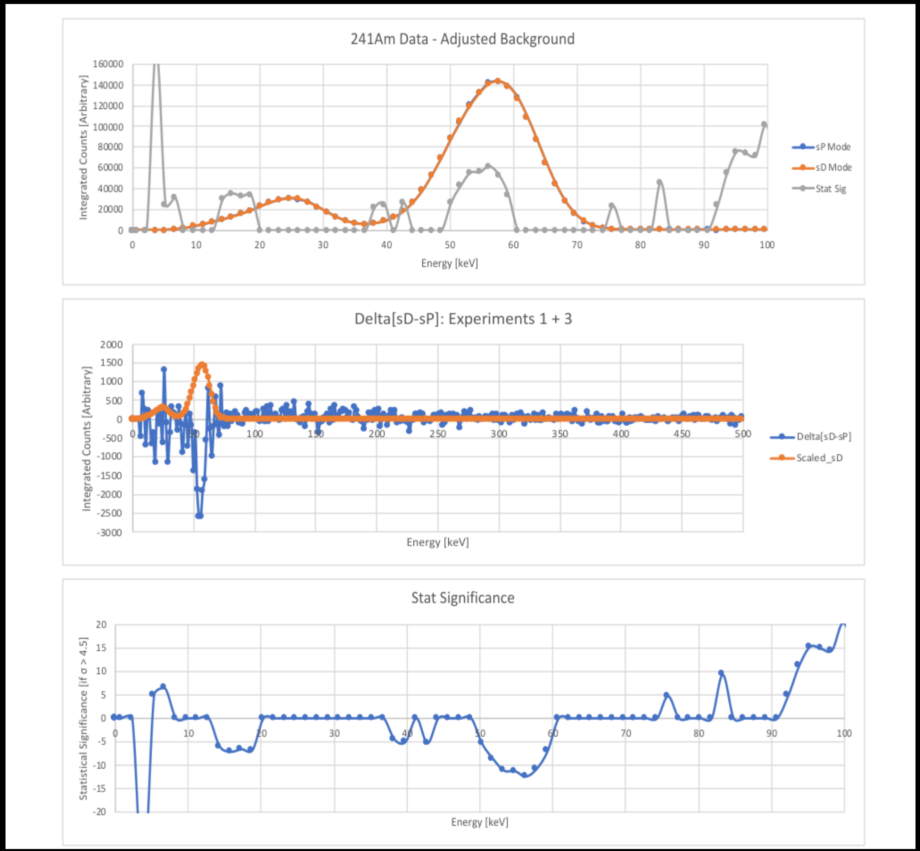


Fig. 5 — BH-mode data over 18 hours: spectrum with significance overlay, Δ(sD−sP), and the resulting sliding-window significance

6.49σ

peak statistical significance after 18 hours of BH-mode data, centered on the 59.54 keV line

- Δ(sD−sP) tracks the shape of the 59.54 keV gamma peak itself — not a broad offset across the whole spectrum.
- The effect is reproducible across repeated runs within Experiment 1.
- This is the first indication that the sP and sD modes differ near the target gamma line.

Independent Validation: Second Experiment

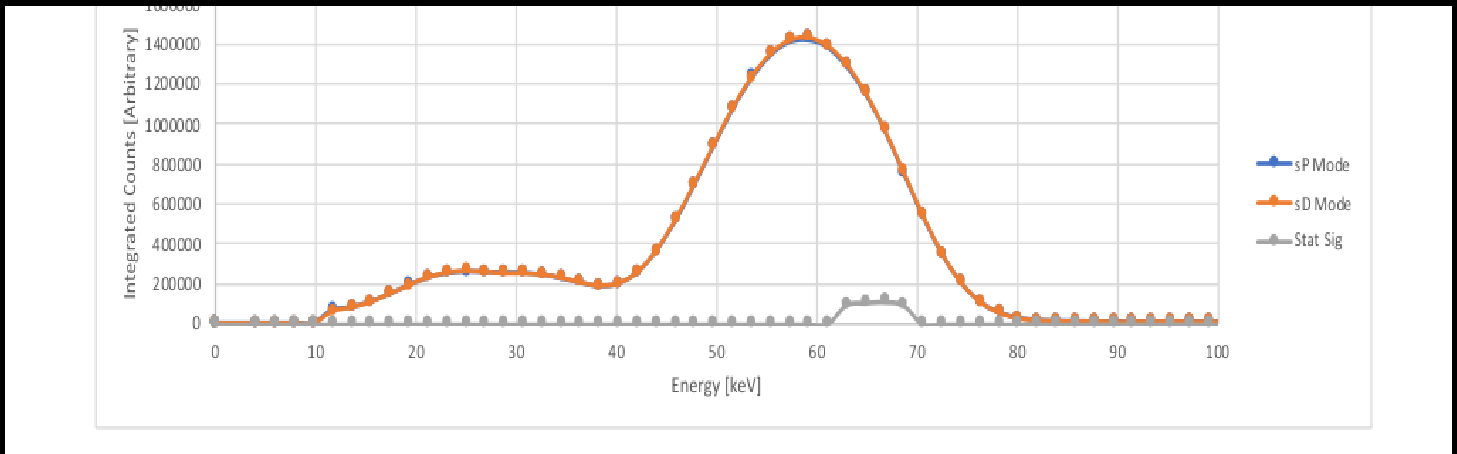


Fig. 7 — Experiment 2: combined BH+BV cumulative spectrum with overlaid statistical significance, 48-hour integration

- New hardware: blue 445 nm laser, mirror cavity, different NaI detectors, field raised to 130 mT
- sP and sD alternated every 15 minutes over 48 hours combined.
- Same analysis pipeline as Experiment 1 — sliding-window significance near the target gamma lines.

5.49σ

independent deviation observed at 66.84 keV, adjacent to the 59.54 keV peak, from a fully separate apparatus

Different laser, different detectors, different day and same effect.

Estimating the Cross Section

The combined production–absorption cross section $\sigma_{\gamma\gamma} \cdot \sigma_{\alpha n}$ is extracted from the measured Δ[Decay] = (sD − sP) near the 59.54 keV peak.

	Experiment 1: BV	Experiment 1: BH	Experiment 2: BH–BV
Δ[Decay]	~ 550	~ 15,167	~ 6,300
$\sigma_{\gamma\gamma} \cdot \sigma_{\alpha n}$	(null)	**5.95×10^{-30} cm²**	**4.52×10^{-30} cm²**

- Order-of-magnitude consistent with weakly coupled ALP models proposed in the literature.
- Precision is currently limited by the geometric factor, integration time, and detector resolution not by a lack of signal.
- The BV (null-test) configuration yields no resolvable cross section, as expected if the effect requires $E \cdot B \neq 0$.

Implications and Future Work

Implications

- Consistent with photon→ALP conversion via the Primakoff mechanism.
- Geometry (BH vs. BV) dependence supports a pseudoscalar coupling, not an artifact.
- Suggests a new, indirect channel for ALP detection: nuclear decay-rate modulation.
- Complementary to haloscope and helioscope axion searches.

Future work

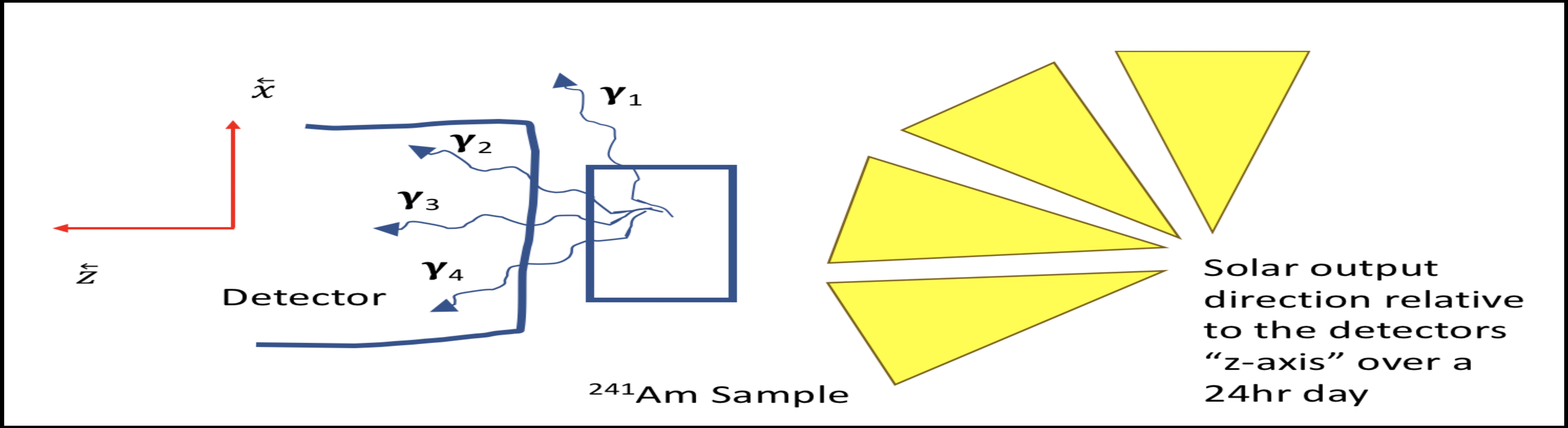
- Extend the method to ^{137}Cs (661.7 keV) and ^{238}U for isotope-independence checks.
- Increase integration time for stronger statistical confidence.
- Explore other laser wavelengths and higher field strengths.
- Develop real-time / pulsed ALP modulation tests and resonant cavity coupling.

Taken together, these results motivate a broader research program: using nuclear decay itself as a novel, low-background channel for axion-like particle searches.

Solar Axions

Solar Axions: Another Important Background

- Independently measuring ^{241}Am decay oscillations over time to search for correlations with solar phenomena.



Every photon reaching the Earth from the Sun, must pass through the Solar magnetic fields. During events such as Coronal Mass Ejections (CMEs) or Solar Flares, the numbers of axions emitted may increase. This could lead to correlations between space weather and ^{241}Am Decays.

A Reproducible Signal in ^{241}Am Decay

- A statistically significant (>6σ) sD−sP difference observed in ^{241}Am decay when the field is aligned (BH).
- The effect vanishes in the BV null-test configuration, as theory predicts.
- Independently reproduced with a second, distinct apparatus (5.49σ).
- Cross-section estimates of order 10^{-30} cm^2, consistent with weak ALP–nuclear coupling.
- A first indication that the Primakoff mechanism may leave a measurable imprint on nuclear decay rates.

Thank You

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Questions are welcome.