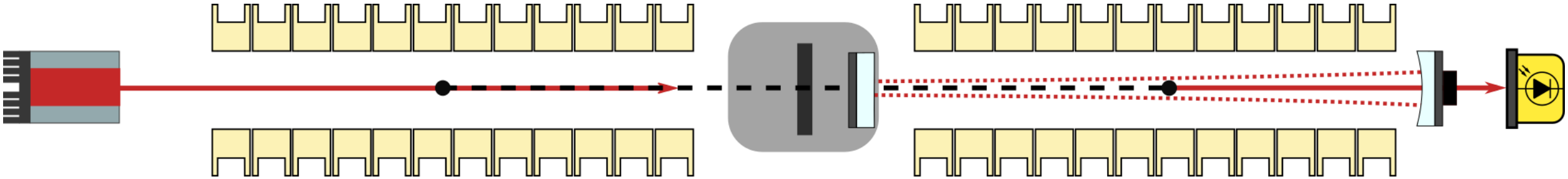
Data Analysis for ALPS II's Initial Science Campaign

20th Patras Workshop on Axions, WIMPs, and WISPs

Sep 22-26, 2025

Daniel Brotherton

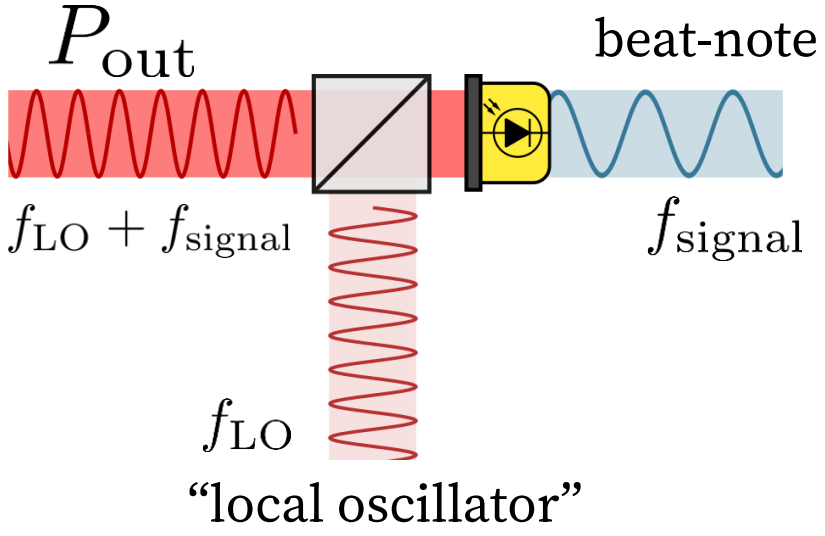
Light-Shining-Through-a-Wall Experiment



$$P_{\mathrm{out}} = P_{\mathrm{in}} \left(\frac{1}{2} g_{a\gamma\gamma} B L \right)^4 \eta \, \beta_{\mathrm{RC}}$$

- search for axions & axion-like particles < 10^{-4} eV
- “Initial Science Campaign” conducted in 2024 without Production Cavity before the wall
- for optical system’s details and future upgrades: Henry Frädrich

Heterodyne Detection



- Interfere reconverted light with a 2nd field to produce a beatnote
  - we can choose its frequency!
- Beatnote is demodulated at the chosen frequency
- Demodulated signal is a complex number, averaged over time for signal-to-noise

$$Z = \frac{1}{N}\sum_{n}^{N} H[n], \quad |Z|^2 \propto P_{\text{out}}$$

beat-note demodulation

$$H[n] = A\,\cos(2\pi f_{\text{signal}} t[n] + \phi) \times e^{i2\pi f_{\text{signal}} t[n]} = \frac{A}{2}\left(e^{-i\phi} + \cdots\right)$$

filtered

Calibration

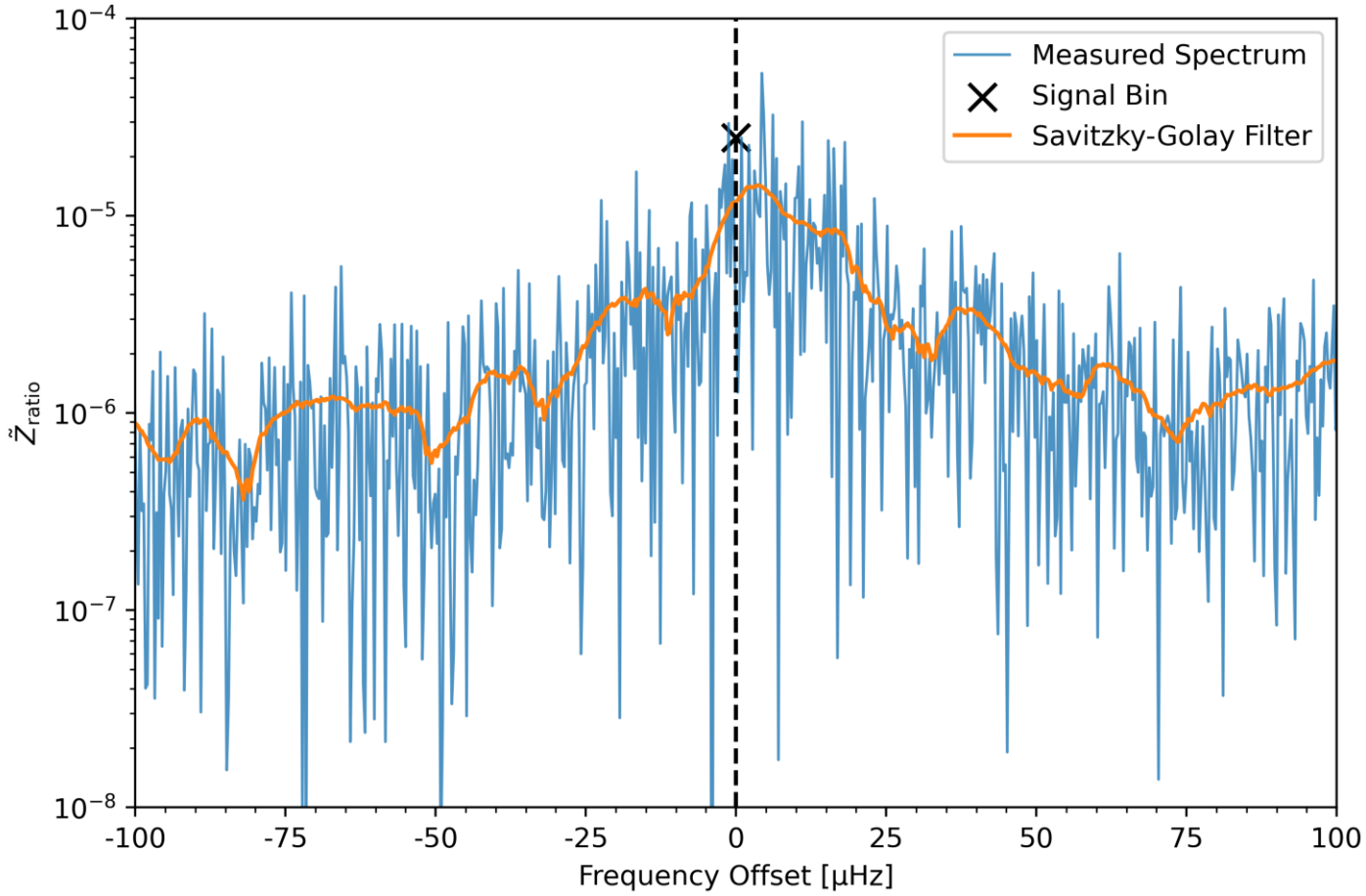
- Ratio of closed-shutter to open-shutter runs:
  - Time-varying systematics cancel out, static parameters easy to measure

$$P_{\mathrm{out}} = P_{\mathrm{in}} \left(\frac{1}{2} g_{a\gamma\gamma} B L\right)^4 \eta\, \beta_{\mathrm{RC}}$$

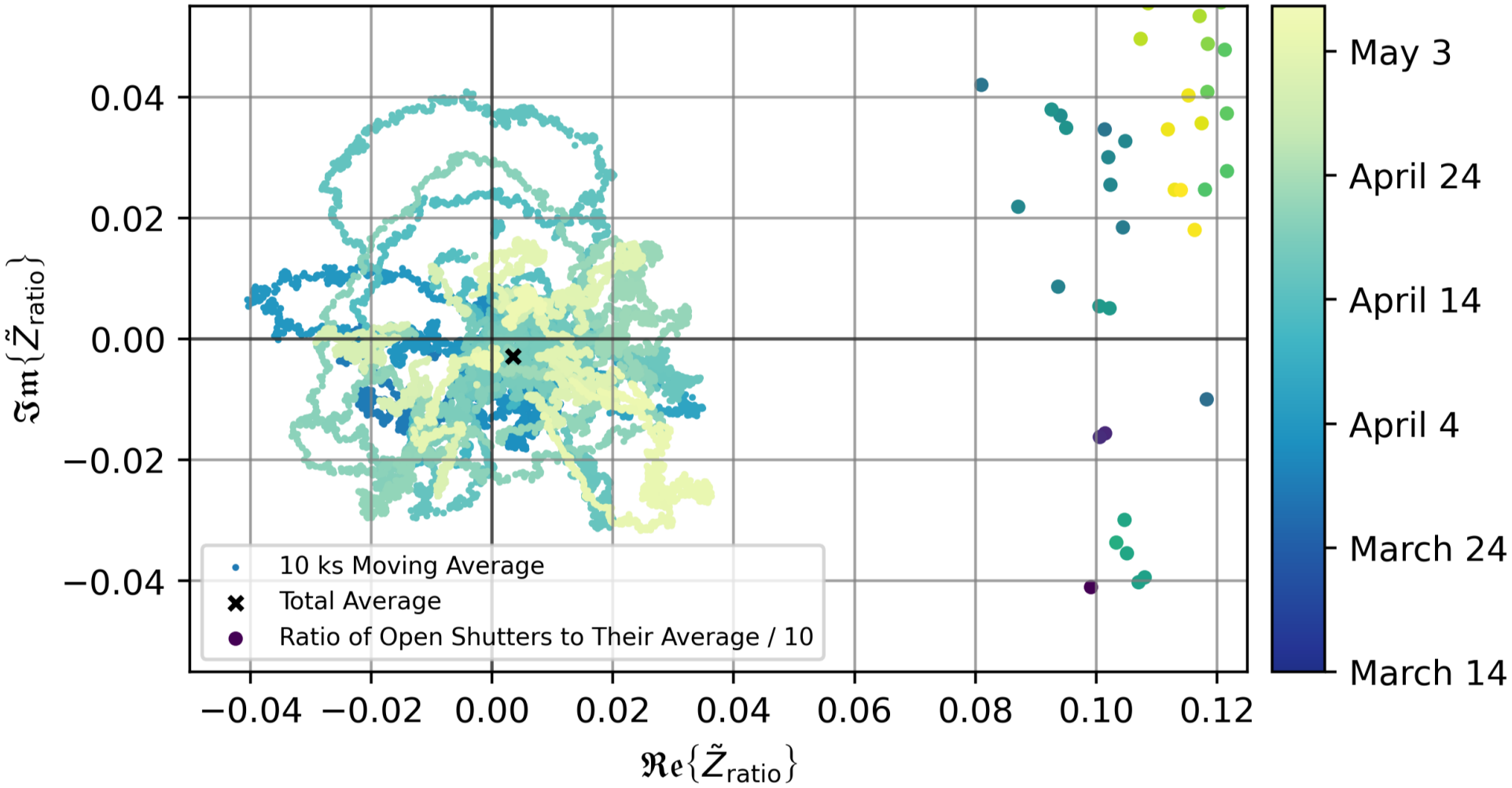
$$P_{\mathrm{open}} = P_{\mathrm{in}}\, T_{\mathrm{diag}} T_{\mathrm{M2}}\, \eta\, \beta_{\mathrm{RC}}$$

$$g_{a\gamma\gamma} = \frac{2}{BL} \left(T_{\mathrm{diag}} T_{\mathrm{M2}} \frac{P_{\mathrm{out}}}{P_{\mathrm{open}}}\right)^{1/4}$$

Stray-Light

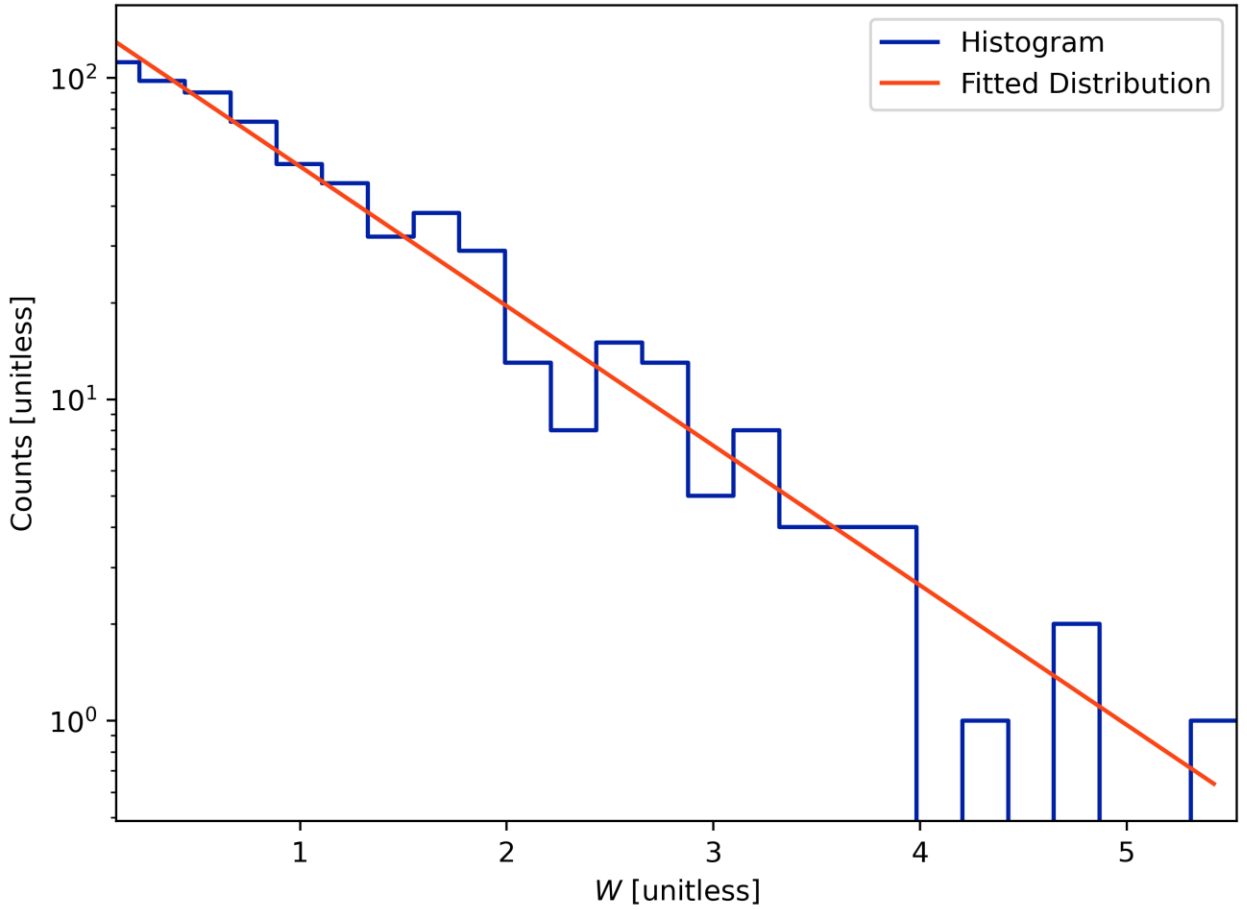

Measured Spectrum
Signal Bin
Savitzky-Golay Filter
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
$\tilde{Z}_{\text{ratio}}$
-100
-75
-50
-25
0
25
50
75
100
Frequency Offset [μHz]

Stray-Light


0.04
0.02
0.00
−0.02
−0.04
$\mathfrak{Im}\{\tilde{Z}_{\text{ratio}}\}$
−0.04
−0.02
0.00
0.02
0.04
0.06
0.08
0.10
0.12
$\mathfrak{Re}\{\tilde{Z}_{\text{ratio}}\}$
10 ks Moving Average
Total Average
Ratio of Open Shutters to Their Average / 10
May 3
April 24
April 14
April 4
March 24
March 14

Stray-Light Statistics

- if no stray-light, statistics are perfectly understood analytically
- For stray-light, alternative frequencies used as a proxy for statistics in the expected frequency bin



Results

- 95% chance to have not missed a 5σ detection
  - Pseudoscalar: $g^{\mathrm{ps}}_{a\gamma\gamma} < 1.4 \times 10^{-9}\ \mathrm{GeV}^{-1}$

    ~20x better than previous LSW experiments!
  - Scalar: $g^{\mathrm{s}}_{a\gamma\gamma} < 1.8 \times 10^{-9}\ \mathrm{GeV}^{-1}$