RESONANT FARADAY ROTATION MEASUREMENTS IN A POTASSIUM VAPOR CELL

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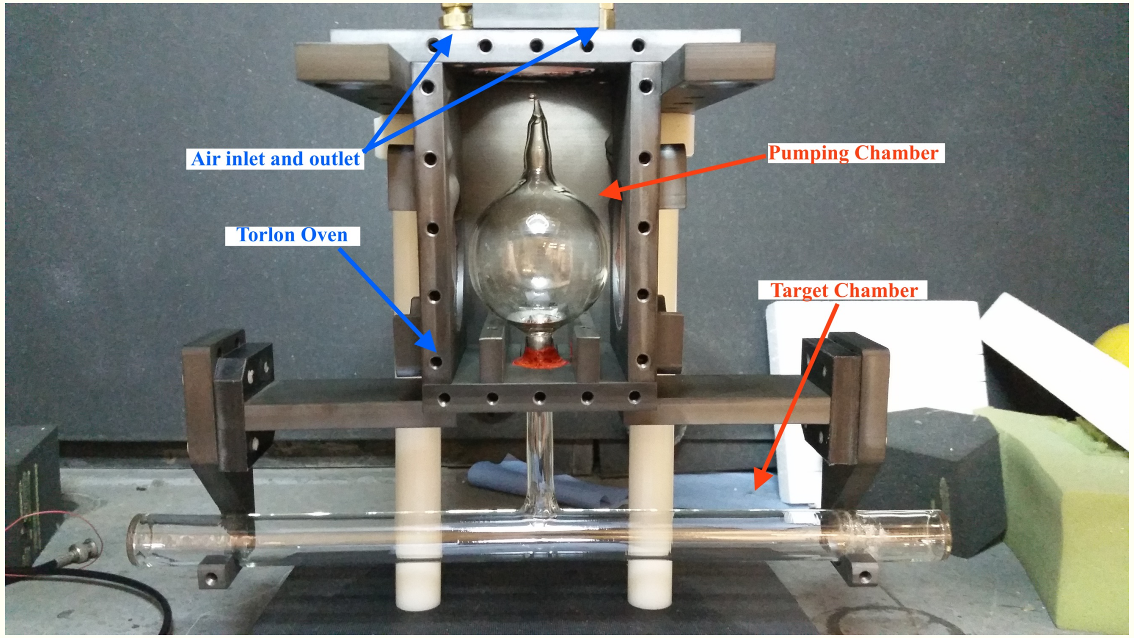
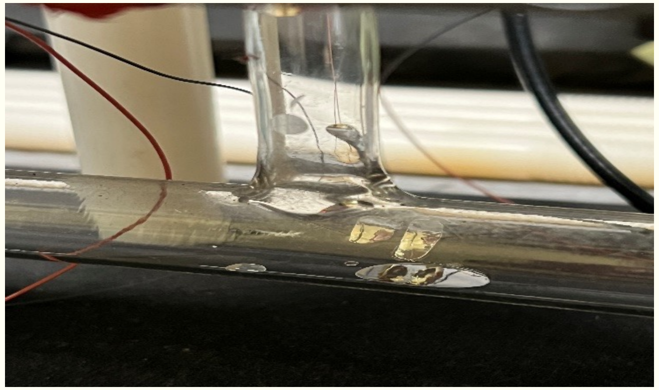
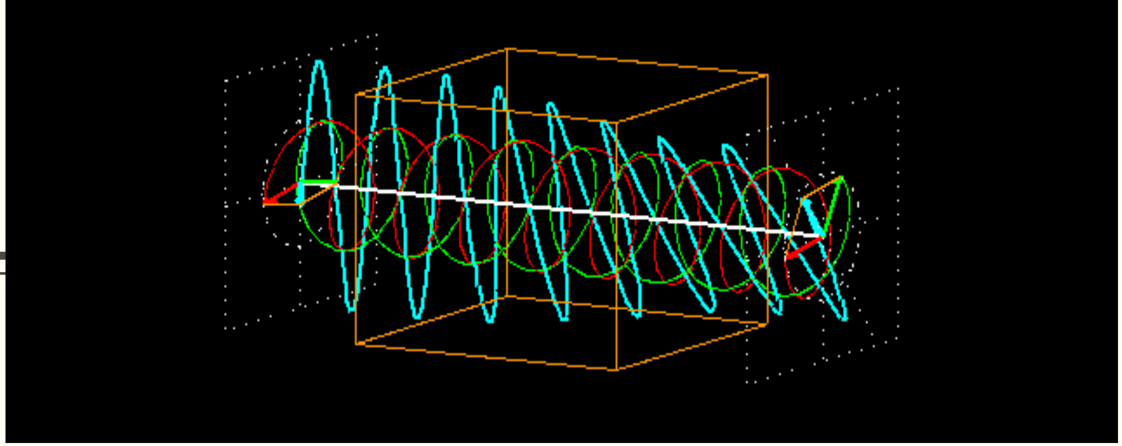
Motivation

- Helium-3 SEOP cell is commonly used for electron scattering experiment at Jefferson Lab to study fundamental structures of neutrons.
- Measuring small change of magnetic field ($\sim 10\ \mathrm{mG}$) due to polarized helium-3 atoms on top of a holding $\overrightarrow{B_0}$-field.
- Alkali metal residue diffusion in the target chamber (TC) due to temperature gradient over time.
- Resonant Faraday rotation on alkali metal D lines.





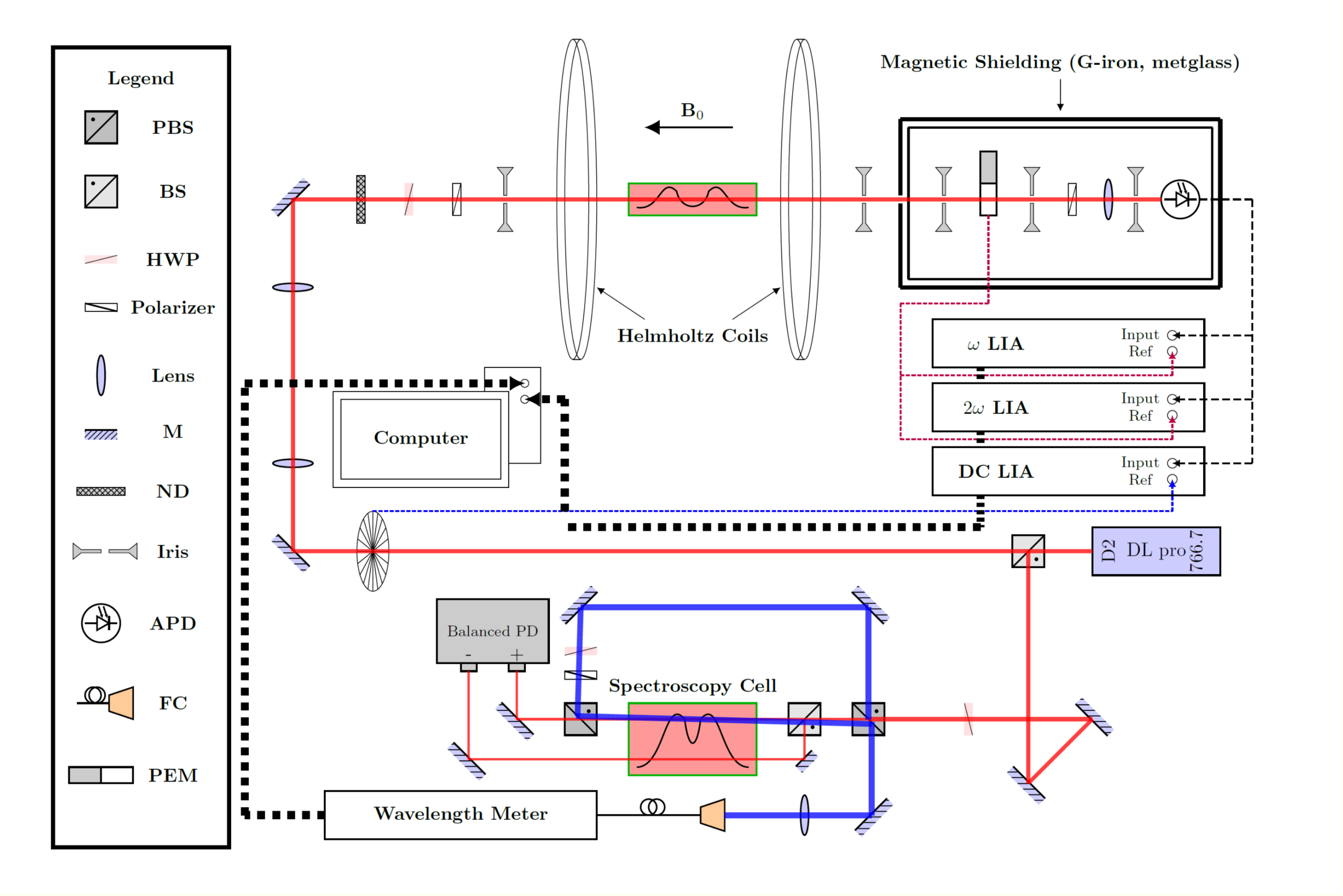
Resonant Faraday effect



- $\theta = \frac{\omega d}{2c}(n_- - n_+)$
- $\theta = [\mathrm{K}]\frac{de^2}{6mc}\left[\left(\frac{1}{\Delta_{3/2}} - \frac{1}{\Delta_{1/2}}\right)P_{\mathrm{K}} + \frac{\mu_B}{3h}\left(\frac{7}{\Delta_{3/2}^2} + \frac{4}{\Delta_{1/2}^2} - \frac{2}{\Delta_{3/2}\Delta_{1/2}}\right)B\right]$
  - Paramagnetic Faraday rotation (power dependent)
  - Diamagnetic Faraday rotation (B-field dependent)
- $P_{\mathrm{K}} = \frac{P_{1/2} - P_{-1/2}}{2}$ denotes the electron polarization of potassium atoms.
- $[\mathrm{K}]$ denotes the number density of potassium atoms.
- $\Delta_{3/2} = \nu - \nu_{3/2}$ denotes the frequency detuning from the center of $4^2\mathrm{S}_{1/2} \rightarrow 4^2\mathrm{P}_{3/2}$, similarly for $\Delta_{1/2}$.

*Kadlecek, S. J. (1999). *Spin relaxation in alkali vapors*. The University of Wisconsin-Madison.

Faraday rotation measurements



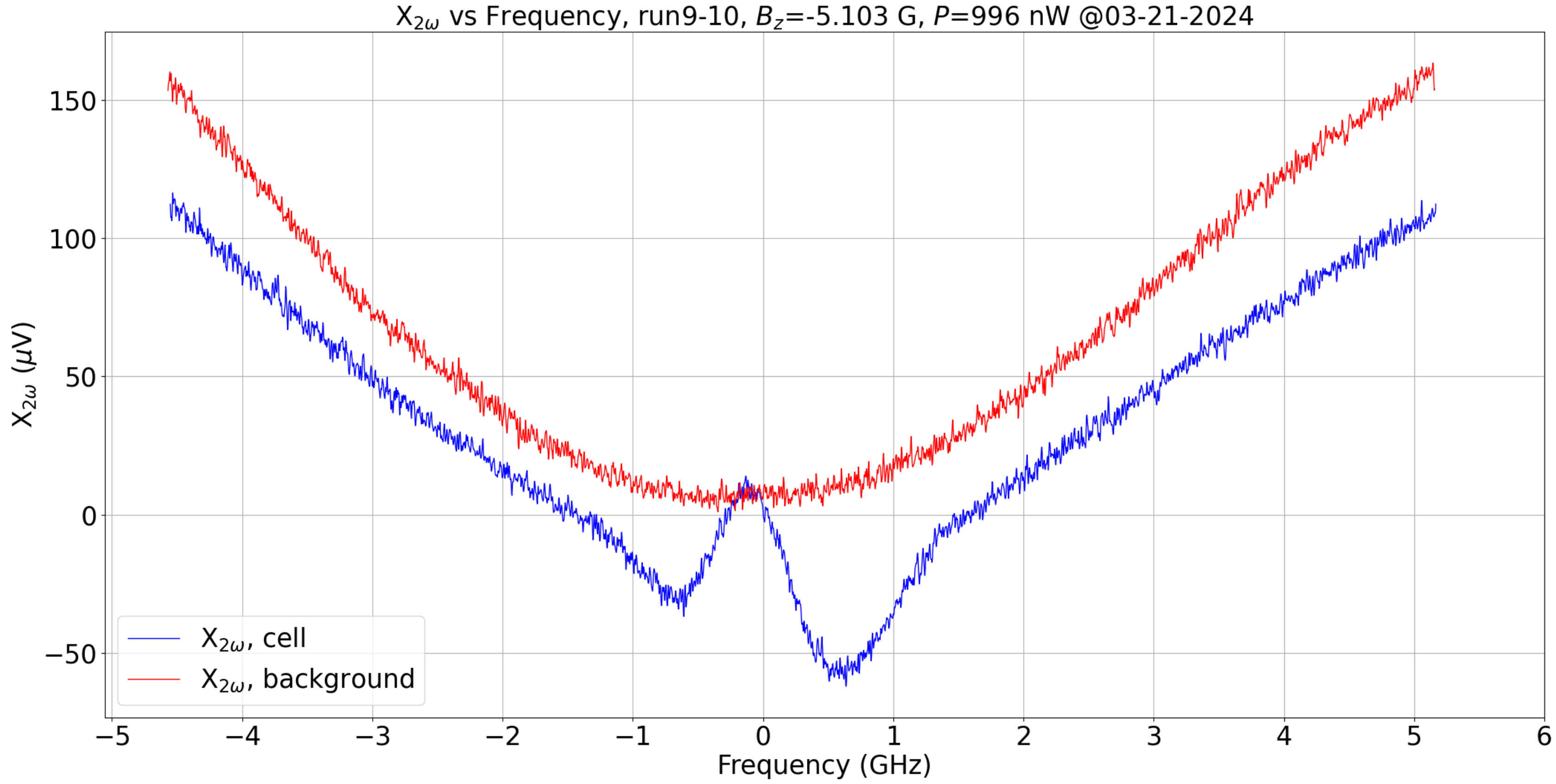
Faraday rotation measurements near potassium D_2 line

- The laser was scanned over a range of ~10 GHz for Faraday rotation measurements, centered on the potassium D2 line, at a scanning speed of ~24 MHz/s.
- Three Lock-in amplifiers (LIAs) are used for data collection and signal processing with time constant set to 100 ms.
- Incorporated a photoelastic modulator (PEM) as a spectroscopic ellipsometer for polarization modulation. In our experimental setup, the LIAs reference to PEM measured V_ω and $V_{2\omega}$ signals.
- An optical chopper installed right next to the light source with a LIA to measure the PEM-modulated signal V_{dc}.

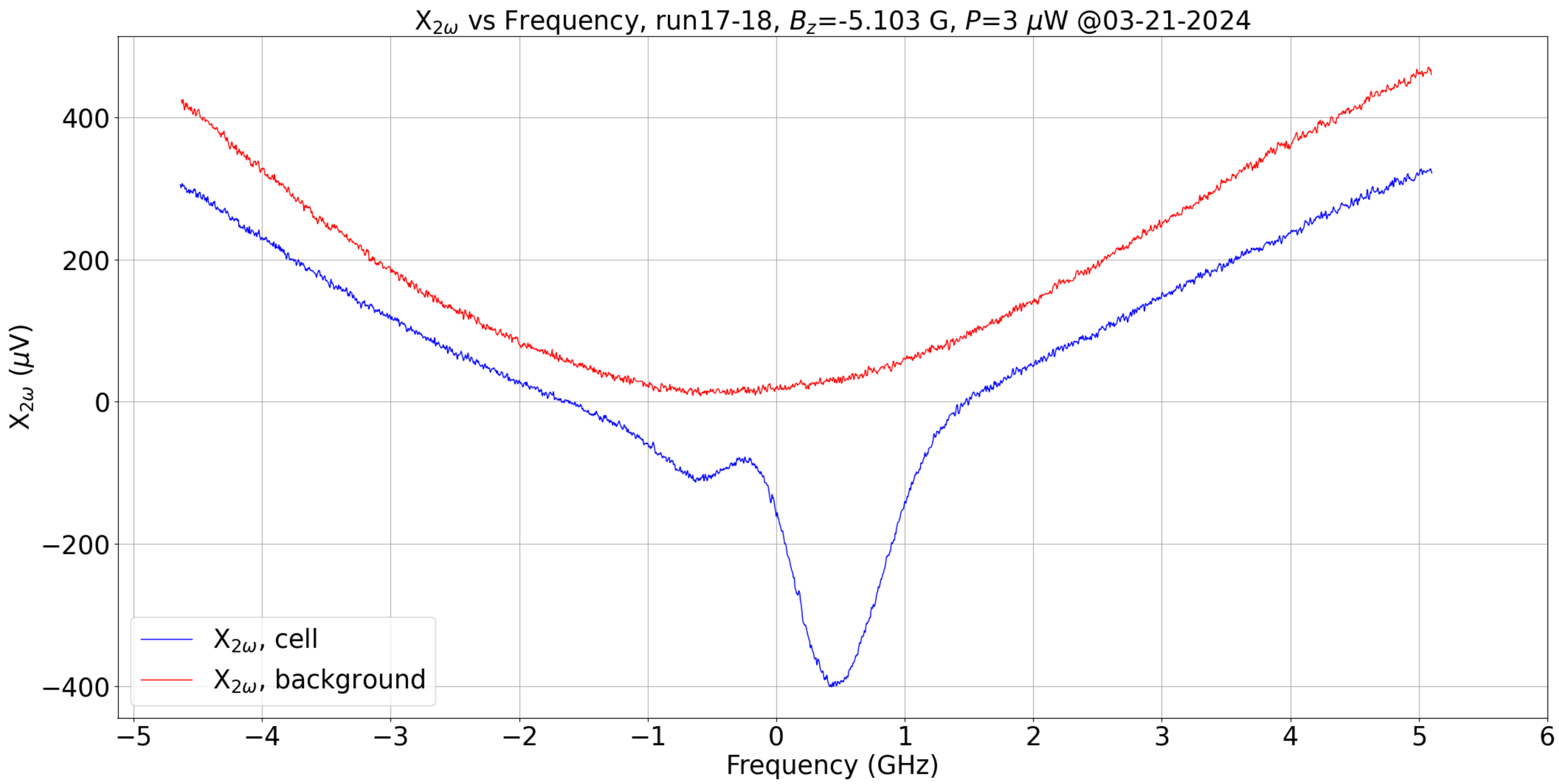
Absorption: $\epsilon = \dfrac{V_\omega}{2\pi J_1(A) V_{dc}}$

Rotation: $\theta = \dfrac{V_{2\omega}}{2\pi J_2(A) V_{dc}\sqrt{1-4\epsilon^2}}$

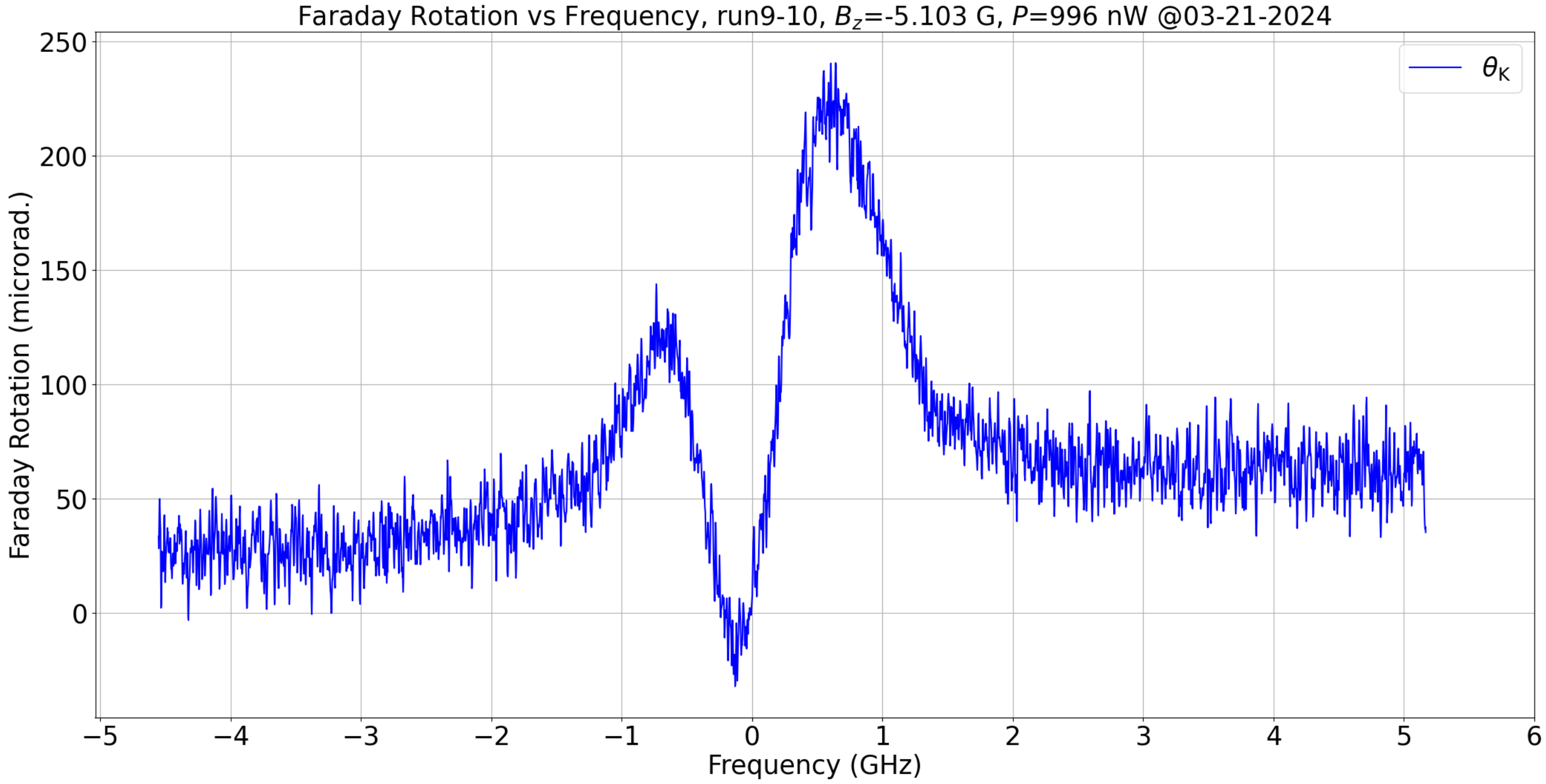
$V_{2\omega}$ vs $\Delta_{3/2}$ at $B_z = -5.103$ G, $P = 996$ nW.



$V_{2\omega}$ vs $\Delta_{3/2}$ at $B_z = -5.103$ G, $P = 3$ μW.



Faraday rotation measurements, $\theta_K = \theta_{cell} - \theta_{background}$



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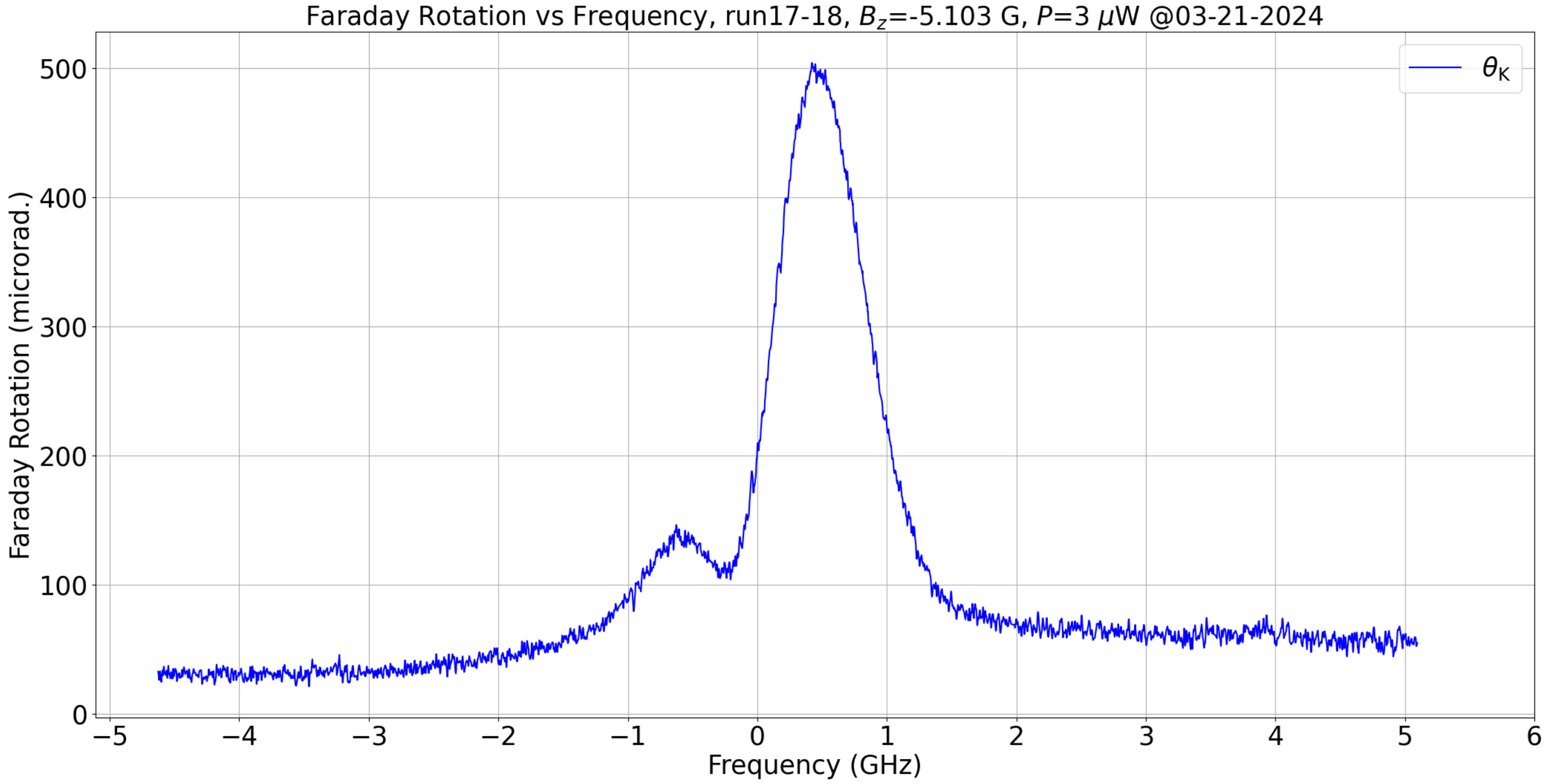


Summary

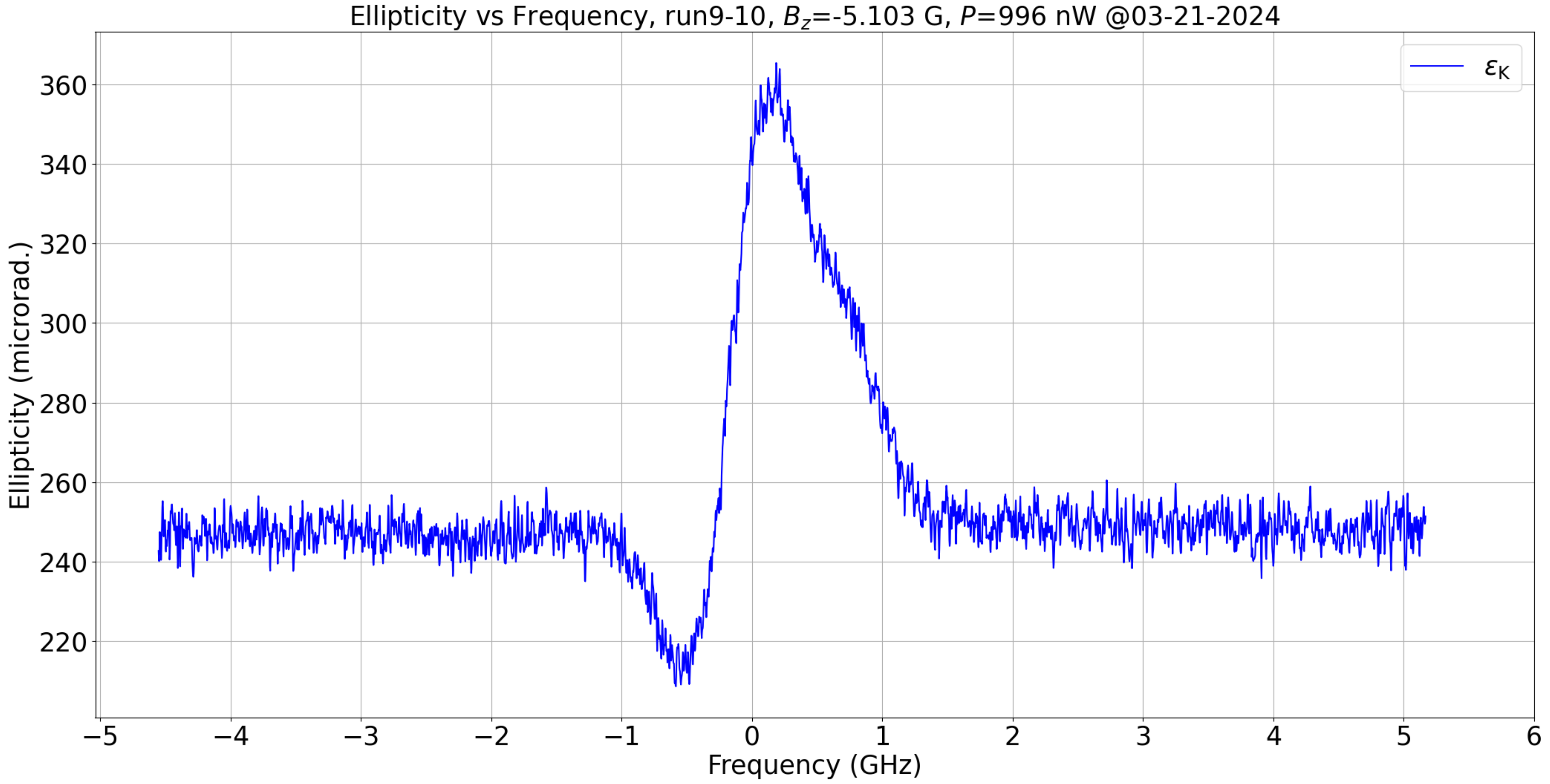
Faraday rotation measurement using PEM ellipsometry with wide scan provides insight to the qualitative behavior between laser power and Faraday rotation angles.

We are actively investigating the effect of paramagnetic Faraday rotation with respect to the power dependence, and this is directly associated with the polarization of potassium atoms, and hence the system is most sensitive at the steepest slope and largest amplitude of the rotation curve.

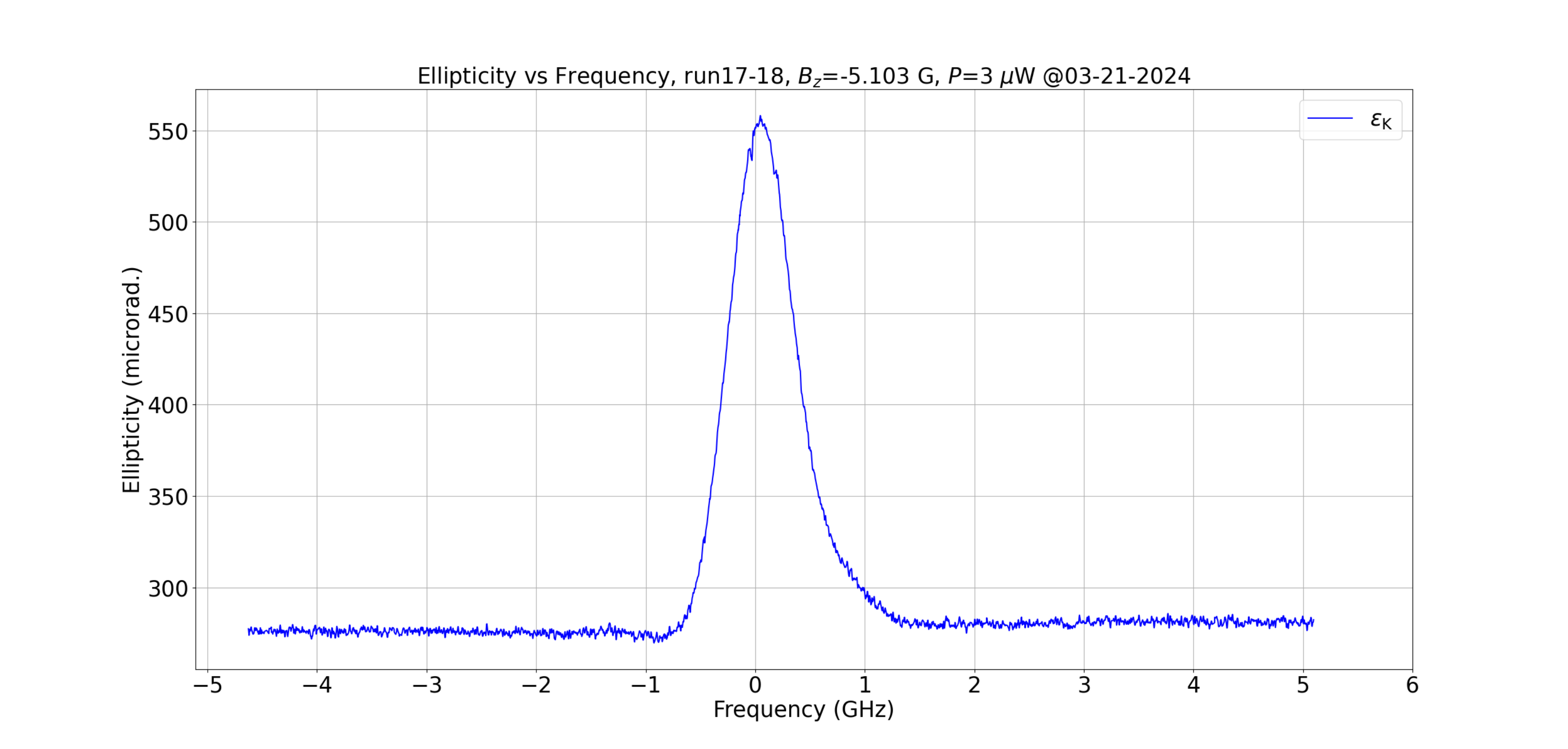
With the high filled density of helium-3 in SEOP hybrid cell, the potassium D lines will experience a significant line broadening and shift, we are planning to utilize EOM and other modulation techniques to further improve our system sensitivity.

BACKUP SLIDES

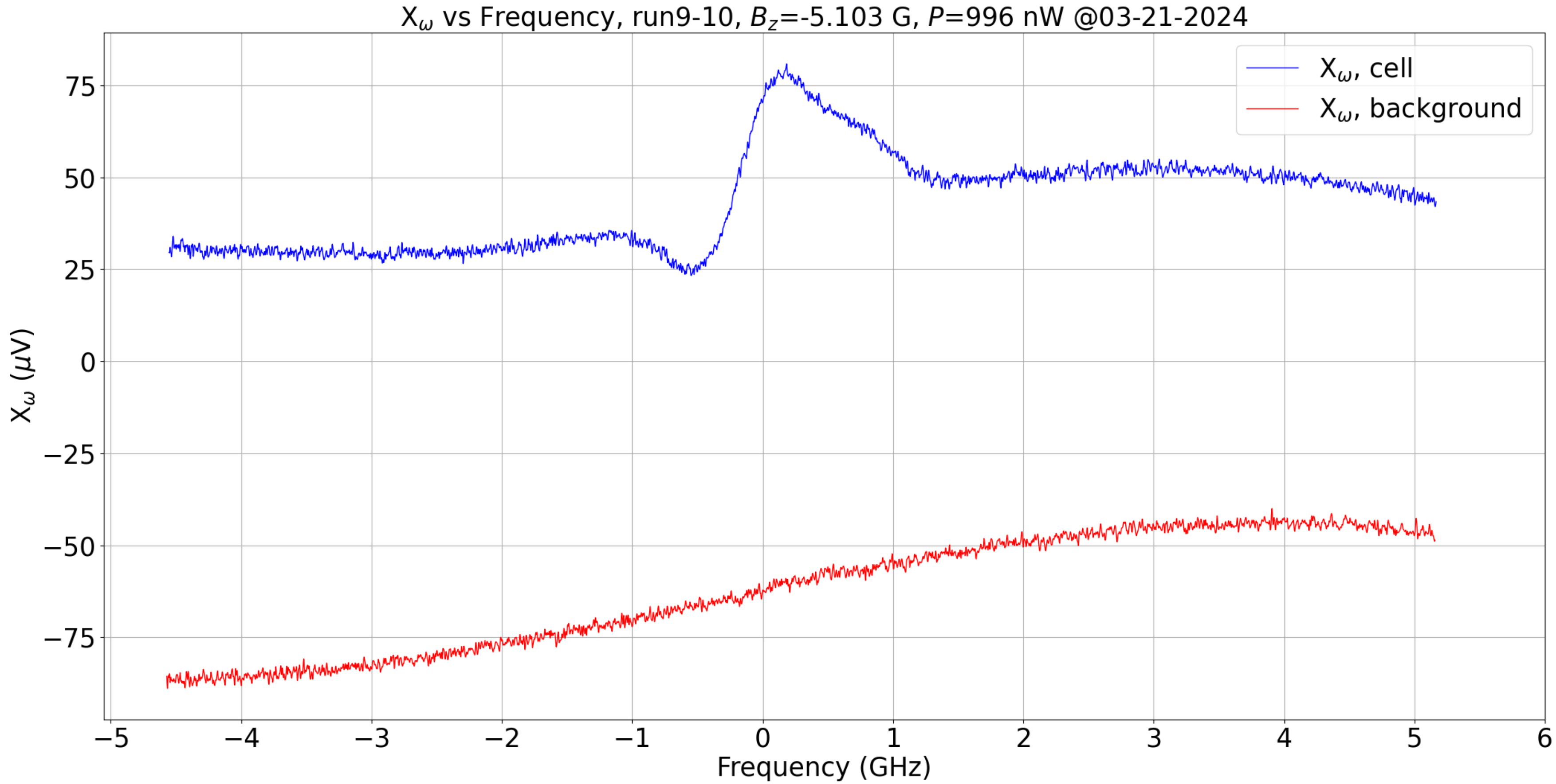
Ellipticity measurements, $\epsilon_K = \epsilon_{cell} - \epsilon_{background}$



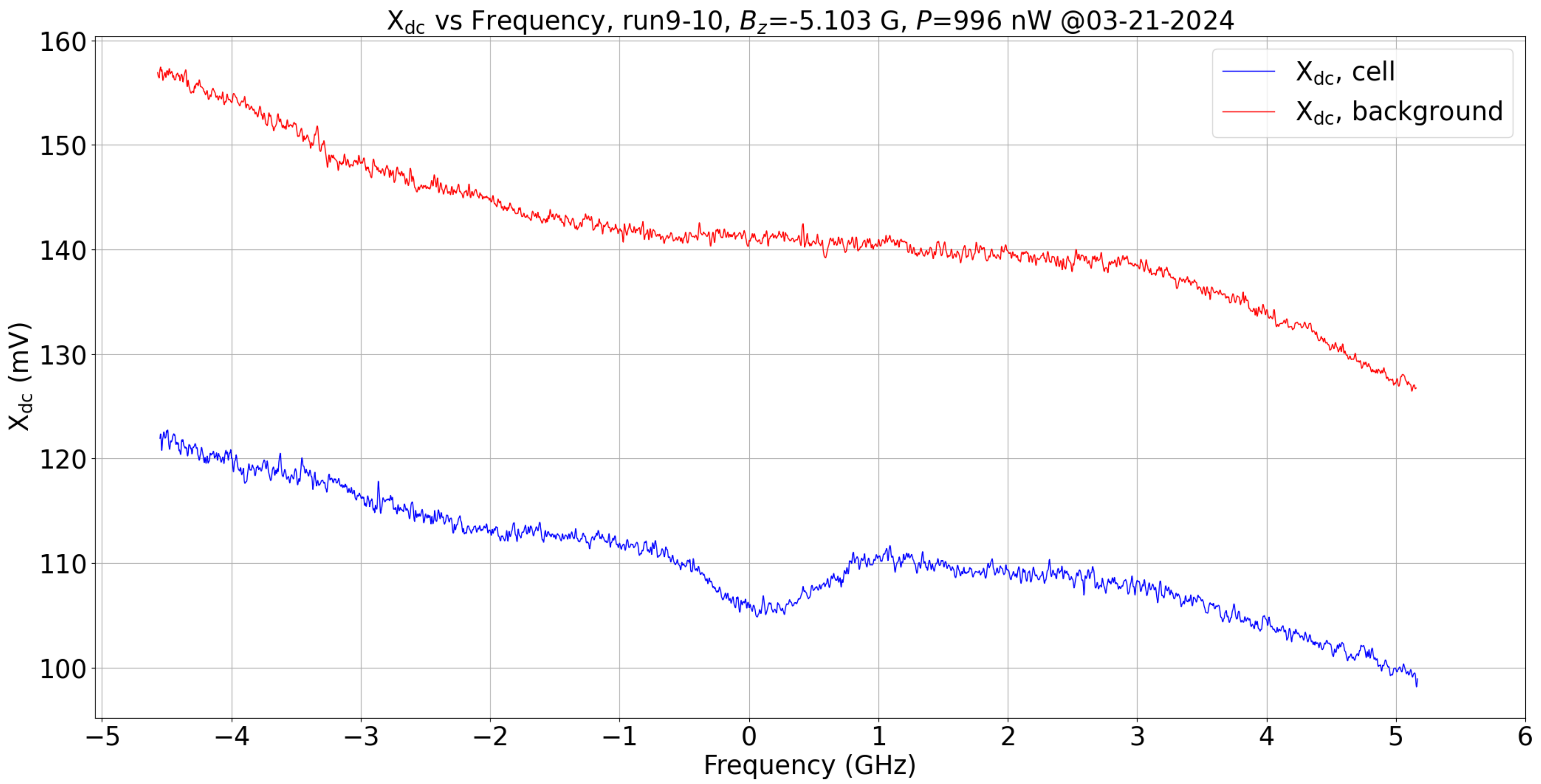
Ellipticity measurements, $\epsilon_K = \epsilon_{cell} - \epsilon_{background}$



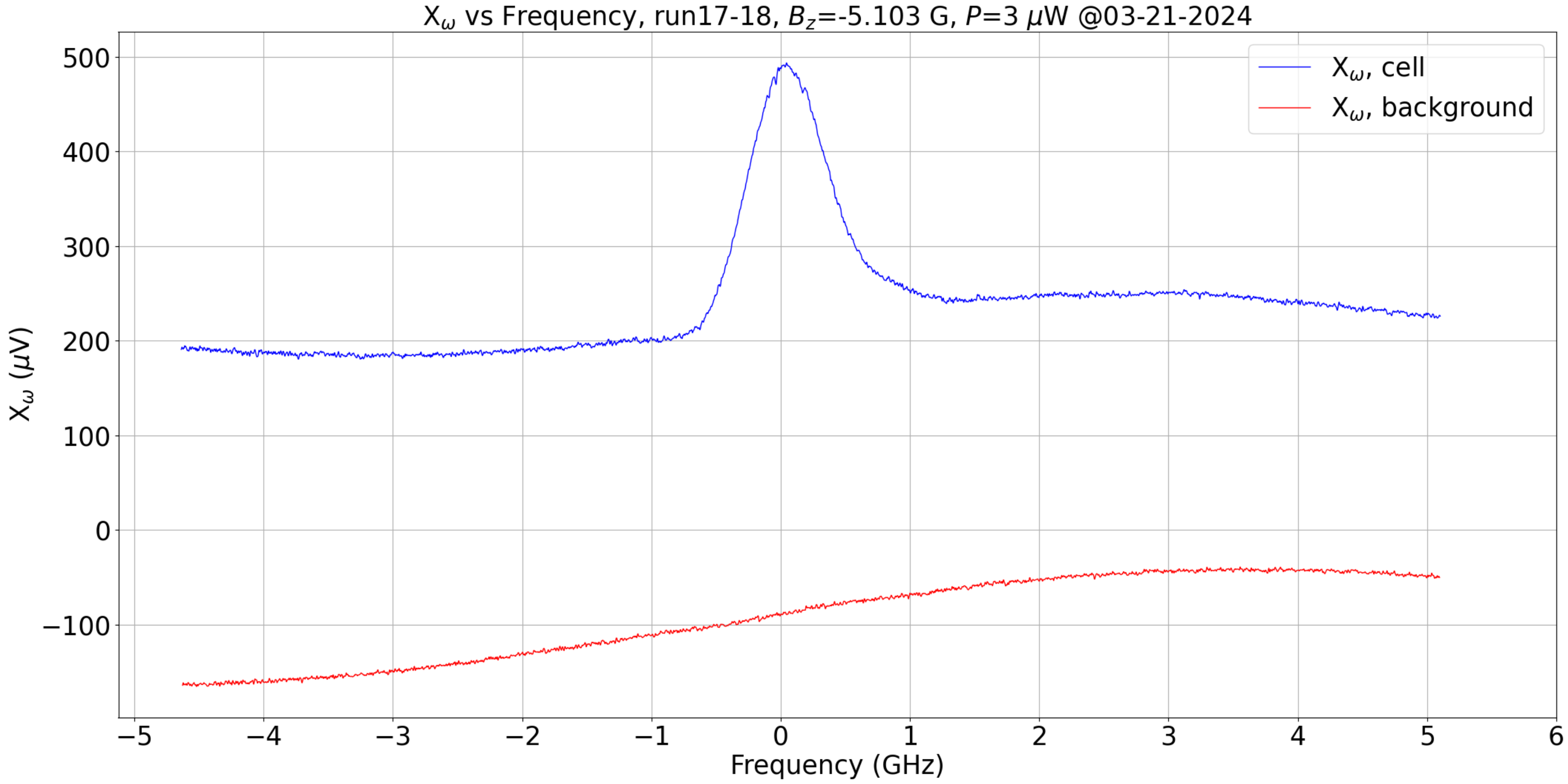
V_ω vs $\Delta_{3/2}$ at $B_z = -5.103$ G, $P = 996$ nW.



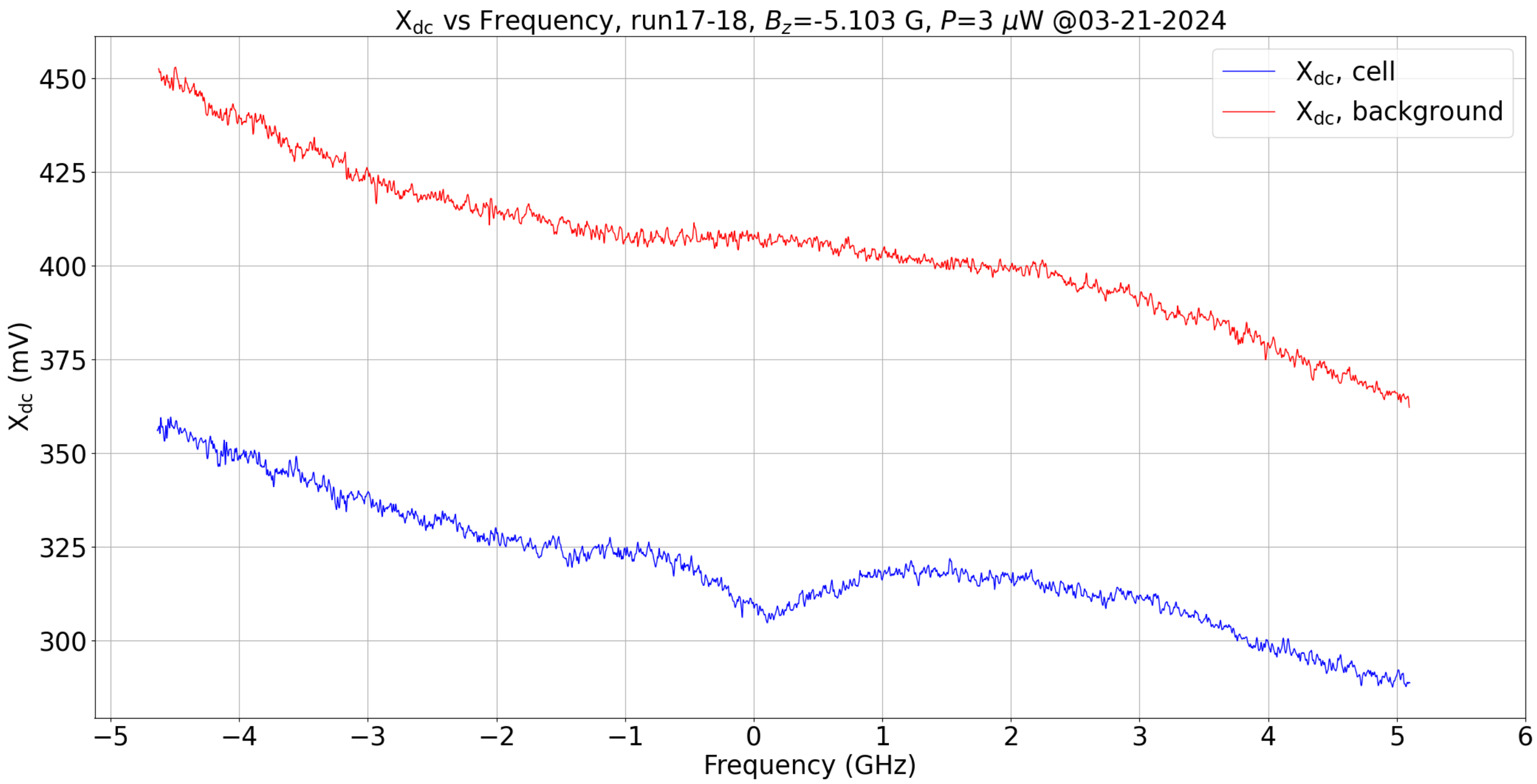
V_{dc} vs $\Delta_{3/2}$ at $B_z = -5.103$ G, $P = 996$ nW.



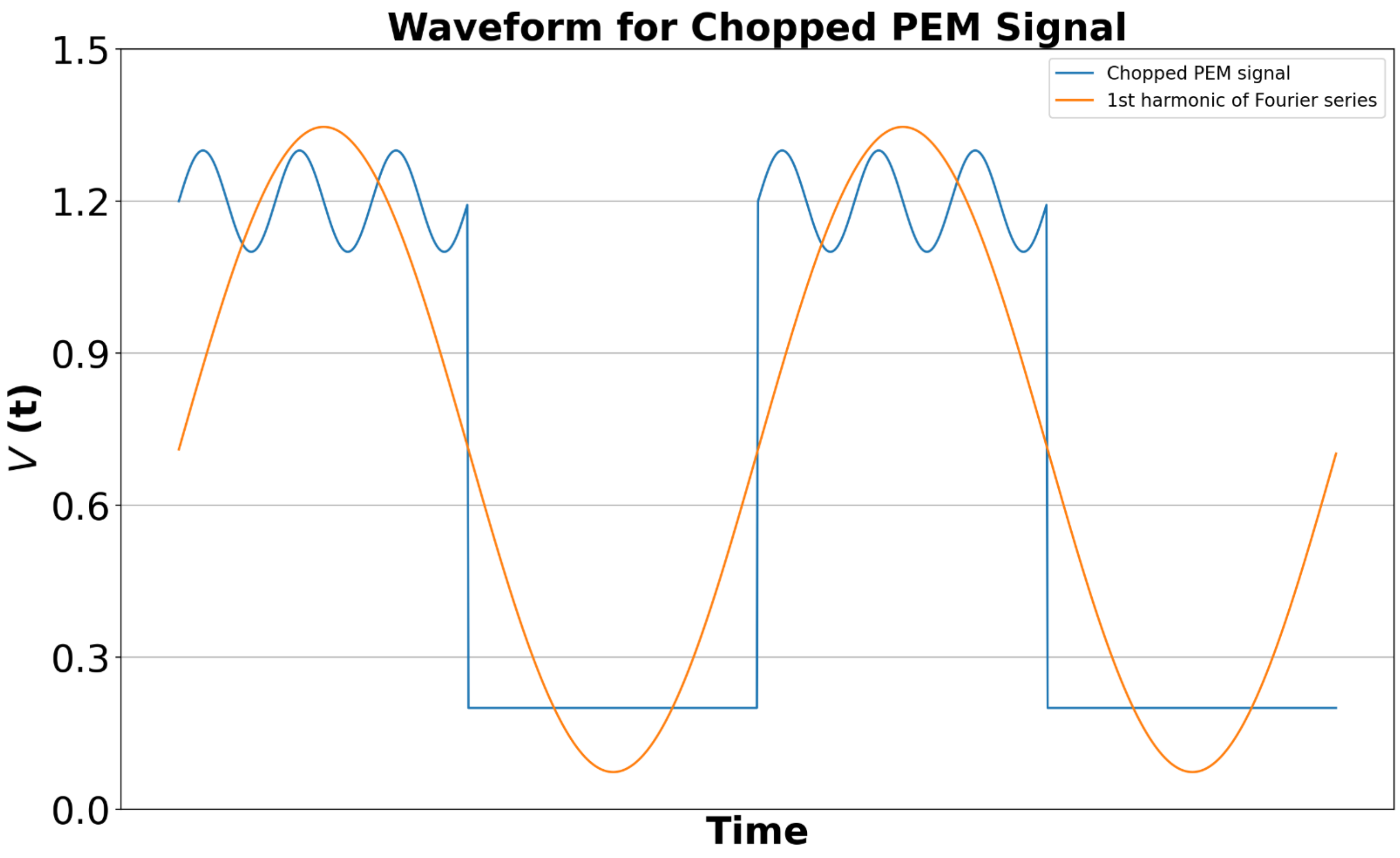
V_ω vs $\Delta_{3/2}$ at $B_z = -5.103$ G, $P = 3$ μW.



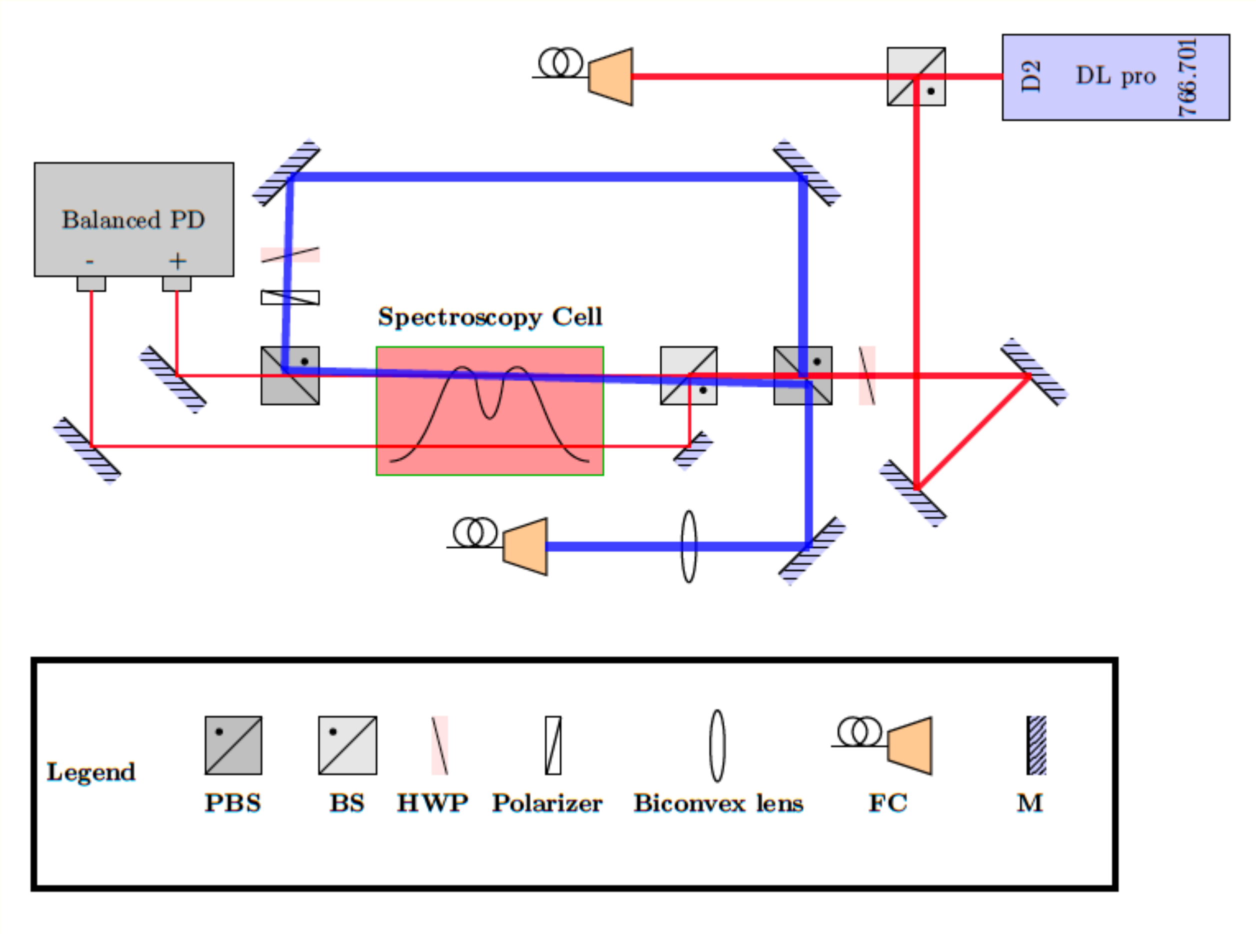
V_{dc} vs $\Delta_{3/2}$ at $B_z = -5.103$ G, $P = 3$ μW.

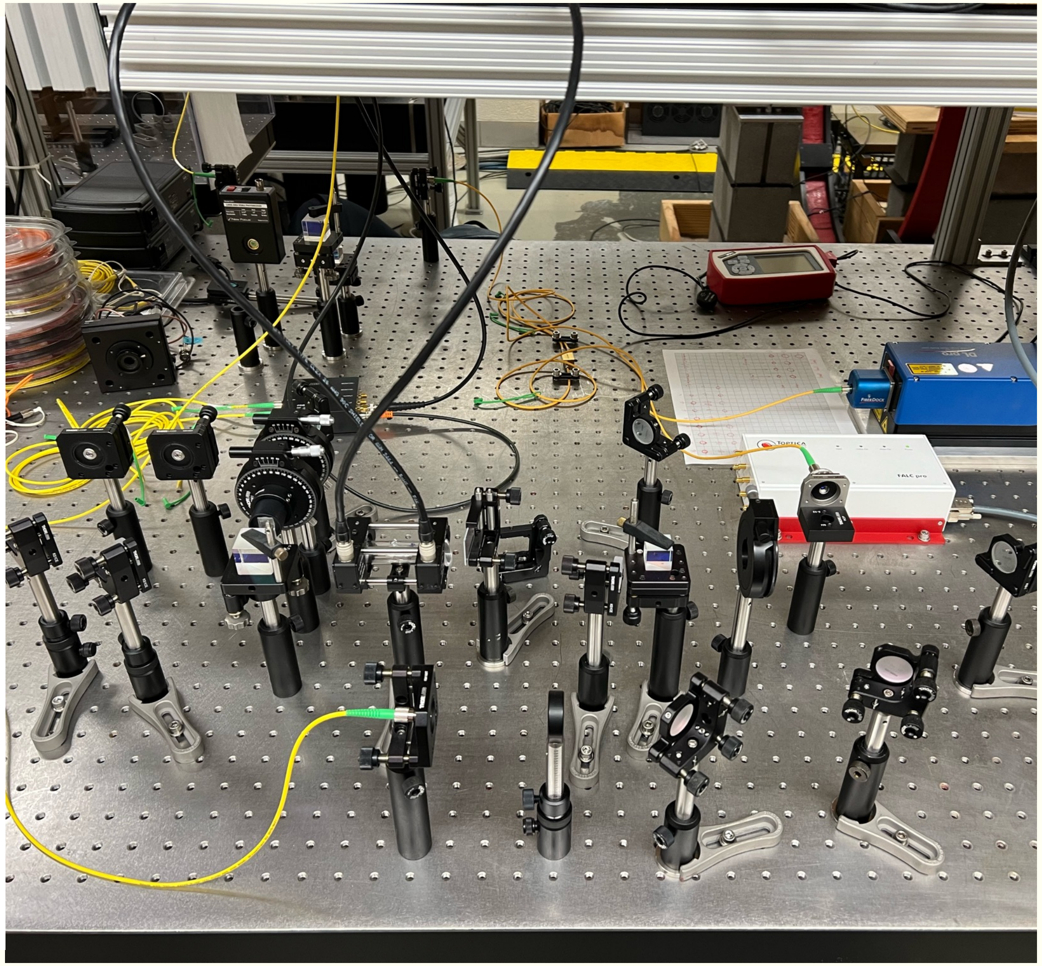


Use mechanical chopper to measure V_{dc}

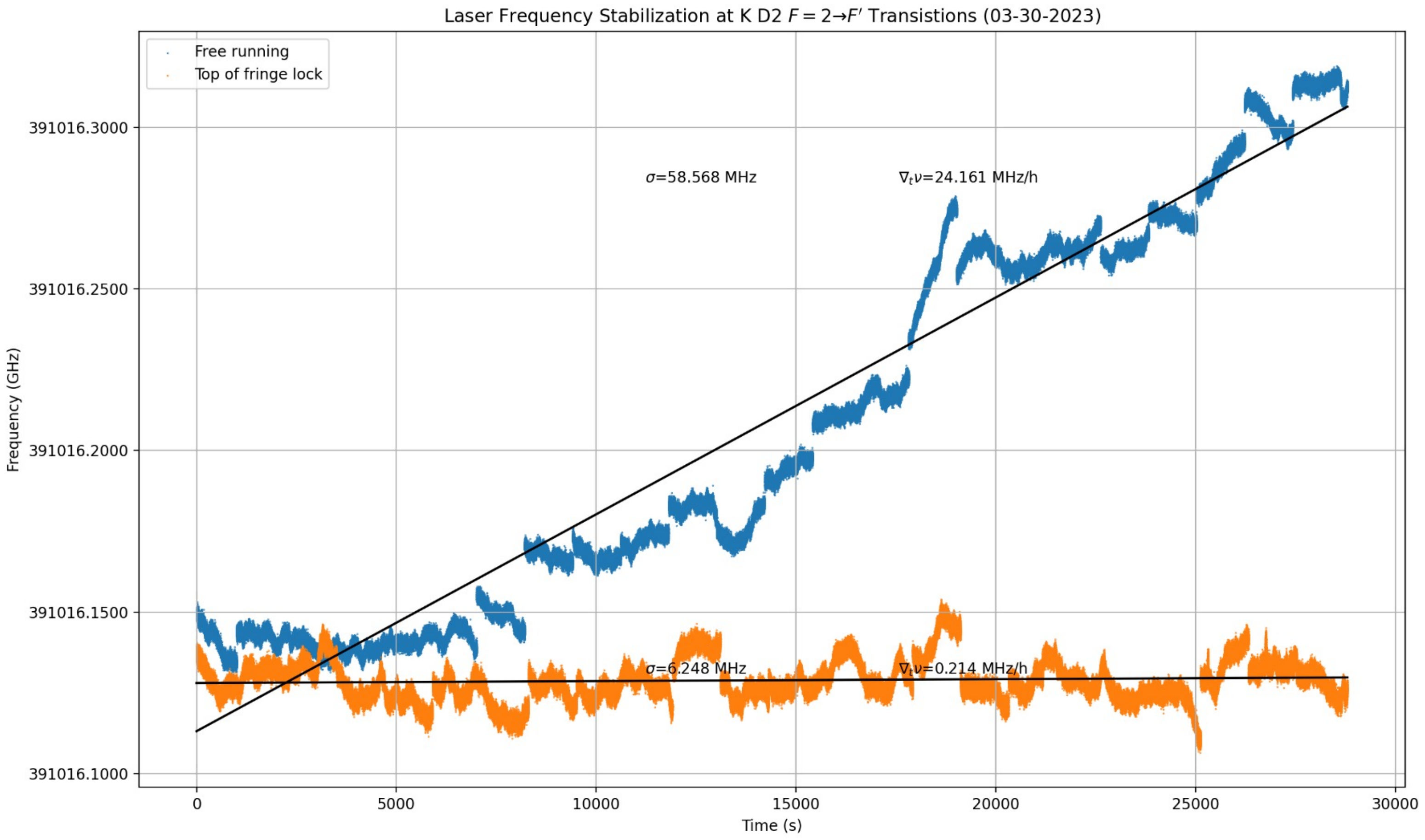


Optics setup of DSAS with K reference cell





Top of fringe laser locking at K D2 line (A feature)



Nonlinear Macaluso-Corbino effect

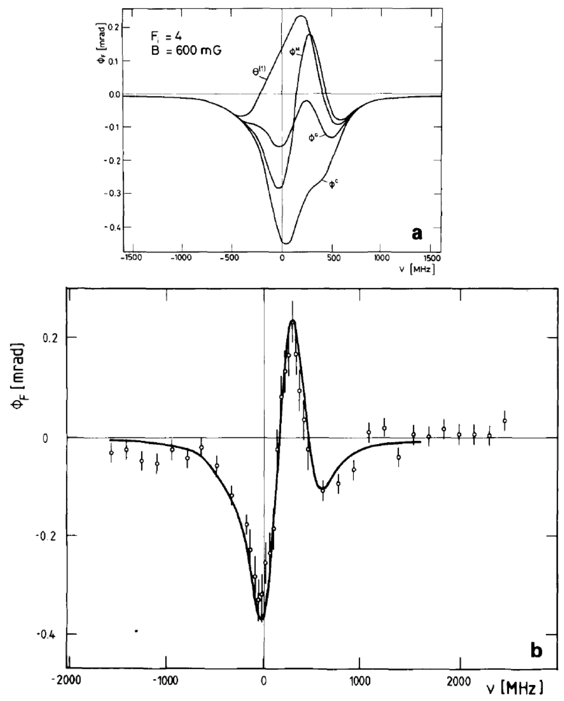


Fig. 2. (a) Theoretical spectra Φ_F (ω, B^*) predicted for $F_i=4$, $\gamma_i=0.32$ MHz, $I=3\times10^{-4}$ W/cm², $B^*=0.6$ G, under various assumptions. $\Phi^G=\Theta^{(1)}+\Theta_0^{(3)}$, $\Phi^C=\Phi^G+\Theta_{fi}^{(3)}$; Φ^M="mutilated" theory. (b) Experimental spectrum Φ_F (ω, B^*), obtained with the same external parameters as (a). The curve corresponds to Φ^M in (a), with a slight (17%) adjustment of the ordinate.

$\Phi_F(B; \omega^*)$ at some fixed ω^*, generally chosen to be the maximum of the absorption. γ_i should be given by the average beam transversal time (see e.g. Shimoda [14]), with some broadening due to laser frequency jitter.

Upon comparing any spectrum $\Phi_F(\omega; B^*)$ taken in the region of the plateau of fig. 1, we found that *neither* $\Theta_0^{(3)}$ *nor* $\Theta_0^{(3)}+\Theta_{fi}^{(3)}$ *fit the data even qualitatively.* We then discovered [8] that a "mutilated theory", i.e. one in which the *population terms* in eqs. (1a) and (1b) *are dropped*, reproduces the spectra very well. This is illustrated in figs. 2a and 2b. In fig. 2a we compare various theoretical spectra, Φ^M representing the "mutilated" theory, while in fig. 2b we compare the latter prediction with experiment (for the same parameters, see caption). This agreement

holds as long as one stays within the plateau of fig. 1; fig. 3 shows an $F_i=4$ series illustrating this (in conjuction with fig. 1). The absolute frequency scale of the experimental spectra was calibrated in terms of the absorption curve. In these figures, $\nu=0$ corresponds to the maximum of the absorption curve. For the $F_i=3$ spectra, not shown here, an equally good agreement is achieved.

The observed quantitative agreement between data and theory is ununderstood for two reasons: (a) the *arbitrary* suppression of the *P*-terms, and (b) the magnitude of the parameter $G_i=\beta^2/\gamma_{fi}\gamma_i$. Since γ_f/γ_i is 20 to 80 under our experimental conditions ($0.07<\gamma_i/2\pi<0.3$ MHz), G_i is very large when $G_f=\beta^2/\gamma_{fi}\gamma_f\sim1$. Thus an expansion to only 1st order in G_i appears unjustified. Physically, a large G_i means that many cycles of optical pumping take place before an atom quits the beam. Furthermore, with γ_i governed by the escape rate, the validity of a stationary treatment is questionable #1.

We have also obtained detailed spectra for the nonlinear Voigt (transverse Faraday) effect [2]. These will be published separately.

It is a pleasure to thank Prof. C. Cohen-Tannoudji, Dr. K.H. Drake, Dr. W. Gawlik, Dr. S. Giraud-Cotton and Prof. J. Mlynek for stimulating discussions. We also thank Dr. P. Jungner for sending us ref. [6] prior to publication. We are greatly indebted to our colleagues, Dr. N. Schlumpf, Dr. D. Zevgolis and Mr. L. Zhao for assistance in the measurement.

#1 This point was raised by Dr. W. Gawlik in a discussion.

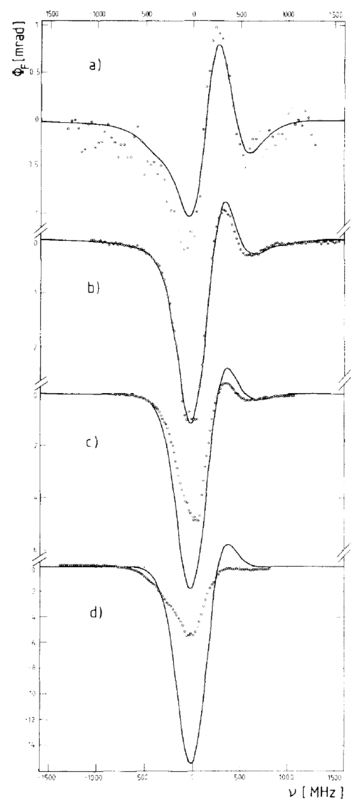
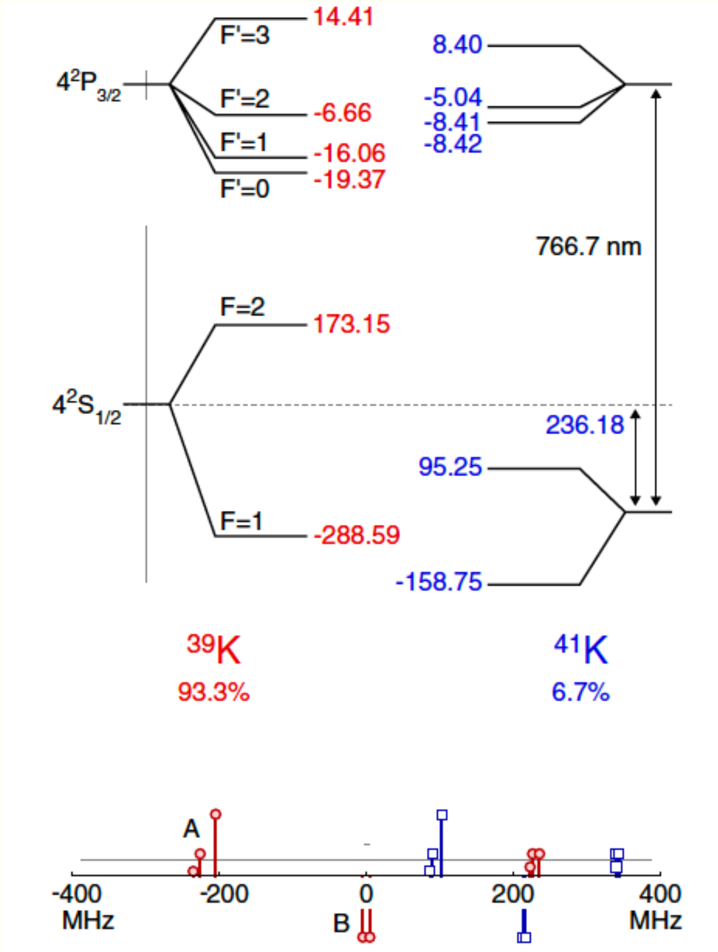


Fig. 3. Series of Φ_F (ω, B^*) for $F_i=4$, at the same B^* (0.2 G), but at increasing intensities. The curves correspond to the "mutilated" theory, with fixed input parameters as given in fig. 1, and the spectra are labeled as in that figure; beam diameter = 0.5 mm. (a) $P_0=2$ µW, $G_f=0.05$; (b) $P_0=6$ µW, $G_f=0.15$; (c) $P_0=15$ µW, $G_f=0.38$; (d) $P_0=50$ µW; $G_f=1.25$.

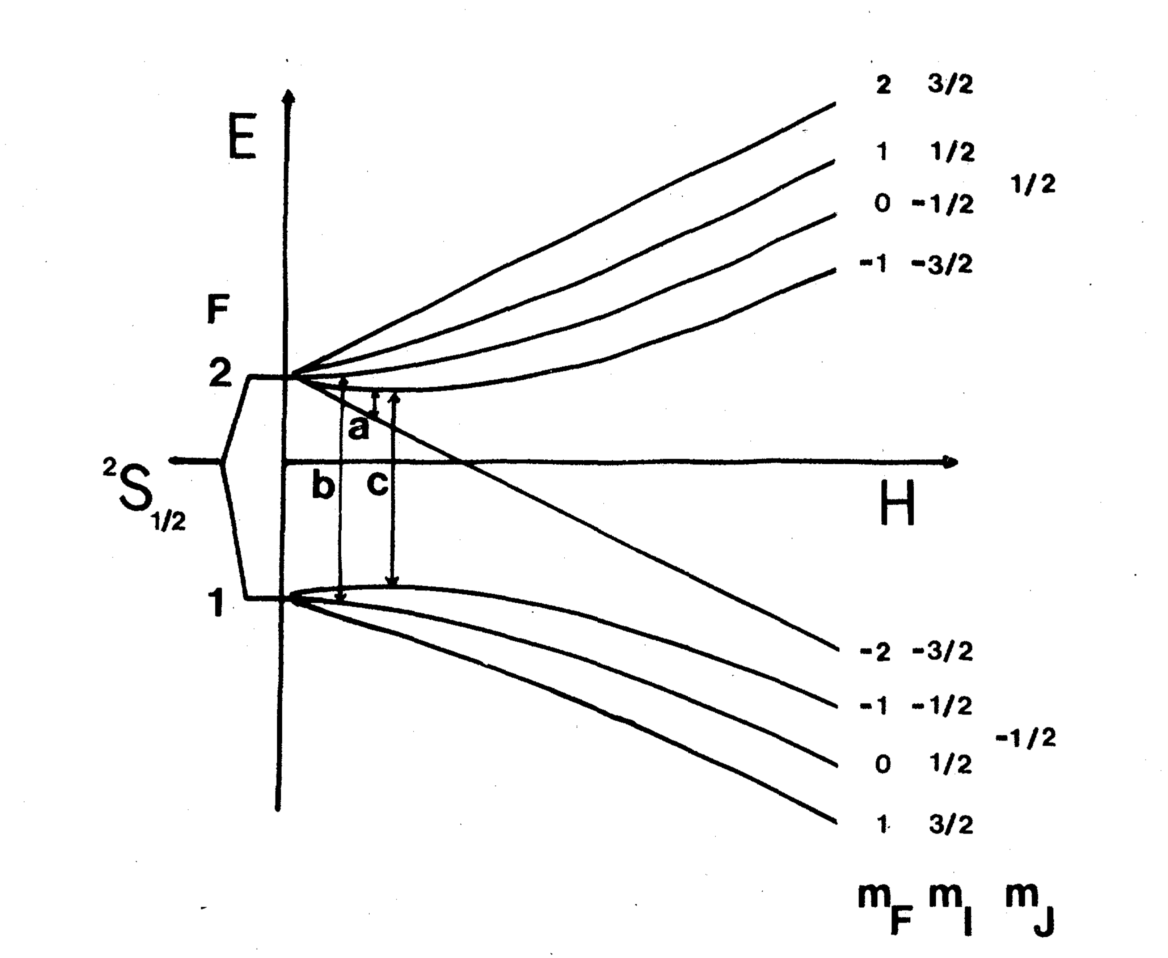
References

[1] W. Gawlik, J. Kowalski, R. Neumann and F. Träger, Phys. Lett. A 48 (1974) 283.
[2] K.H. Drake, W. Lange and J. Mlynek, Optics Comm. 66 (1988) 315;
K.H. Drake, Dissertation, University of Hannover, 1986 (unpublished).
[3] L.M. Barkov, D.A. Melik-Pashayev and M.S. Zolotorev, Optics Comm. 70 (1989) 467.
[4] I.O.G. Davies, P.E.G. Baird and J.L. Nicol, J. Phys. B: At. Mol. Phys. 20 (1987) 5371.
[5] P.E.G. Baird, M. Irie and T.D. Wolfenden, J. Phys. B.: At. Mol. Opt. Phys. 22 (1989) 1733.

Energy level diagram of potassium



Energy level schematics for naturally abundant potassium isotopes.



Energy level diagram in a $S_{1/2}$ state of an atom with nuclear spin 3/2.